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FACTORS LIMITING JUVENILE SOCKEYE PRODUCTION AND ENHANCEMENT POTENTIAL FOR SELECTED B.C. NURSERY LAKES

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ABSTRACT

In this report we present summaries of our current knowledge of freshwater factors limiting sockeye production from 60 B.C. lakes. Data were collected between 1977-2000. Quantity of data available for each lake varied, ranging from intensive multi-year ecosystem studies on some lakes to one-time limnological surveys on others. The lakes are located in five of the six DFO management areas (none are in Yukon-Transboundary). Seventeen of the lakes are in the B.C Interior, eight are in the Central Coast, four are in the Lower Fraser, the majority (25) are in the North Coast, and six are in the South Coast. They make up about two-thirds of the total sockeye nursery lakes in B.C. Their total surface area is 3,586 km², which is approximately 90% of the total area of B.C. nursery lakes. Freshwater factors limiting sockeye production in these lakes are varied, but in the majority of lakes and years fry recruitment is insufficient to fully utilize their productive capacity. Most of the lakes are oligotrophic and strongly nutrient-limited, thus juvenile sockeye growth and/or survival could be improved by nutrient additions. We identify opportunities for enhancement and restoration of the lakes' sockeye stocks, which in addition to lake fertilization include increasing escapements, fry outplants, spawning channels, improvements to spawning grounds, and control of competitors or predators.

RÉSUMÉ

Dans ce rapport, nous présentons un état des connaissances actuelles sur les facteurs dulcicoles qui limitent la productivité du saumon rouge dans 60 lacs de la Colombie-Britannique. Les données présentées ici ont été recueillies au cours de la période comprise entre 1977 et 2000. La qualité de l'information varie, allant des études intensives d'écosystèmes lacustres s'étalant sur plusieurs années jusqu'aux relèvements limnologiques ponctuels. Les lacs que nous avons étudiés sont situés dans cinq des six zones de gestion du MPO (aucun ne se trouvant dans la zone transfrontalière Yukon-C.-B.). Plus précisément, on en comptait 17 dans l'Intérieur de la Colombie-Britannique, 8 dans la région centrale de la côte, 4 dans le bas Fraser, 25 (soit la majorité) dans la région nord de la côte et 6 dans la région sud de la côte, pour une proportion des deux-tiers de l'ensemble des lacs de la Colombie-Britannique où l'on pratique l'ensemencement de saumons rouges et une superficie totale de 3 586 km^2 (soit environ 90% de la superficie totale des lacs ensemencés de la Colombie-Britannique). Les facteurs qui limitent la productivité du saumon rouge dans ces lacs sont variés, mais dans la majorité des zones et des années étudiées, le recrutement s'est révélé insuffisant pour pleinement exploiter la capacité de productivité. La plupart des lacs concernés sont oligotrophes et dans de nombreux cas le taux de croissance et/ou de survie des saumons rouges juvéniles pourrait être amélioré par l'addition de substances nutritives. Nous avons déterminé divers moyens d'améliorer et de restaurer les stocks de saumons rouges de ces lacs : outre les campagnes d'ensemencement, mentionnons l'augmentation du taux d'échappée et du nombre d'écloseries et de chenaux de frai, l'amélioration de la qualité des frayères et le contrôle des espèces concurrentes et des prédateurs.

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I. Introduction

Numbers of anadromous salmon returning to spawn in lakes and streams from Alaska to California have declined dramatically since the early 1900's (Ricker 1987; Gresh et al. 2000). Causes of the reduced escapements vary, but commercial harvesting, industrial development, and habitat degradation have all had substantial impacts. In addition, in the late 1990's rapid declines in numbers of returning adult salmon greatly increased our awareness of the dynamic nature of ocean productivity and its impact on marine survival of salmon. In recent years, the effects of these reductions in salmon escapements on freshwater and terrestrial ecosystems have received considerable attention. The importance of marine-derived nutrients to the productivity of lake, stream, and terrestrial ecosystems is now well documented (Bilby et al. 1996; Larkin and Slaney 1997; Schmidt et al. 1998; Cederholm et al. 1999). It is generally accepted that a major effect of reduced anadromous salmon spawners is the oligotrophication of many lakes and streams, with a corresponding reduction in productive capacity.

For over 20 years, lake fertilization has been a widely used and successful technique for increasing numbers of sockeye salmon in British Columbia and Alaska. For most of this period, lake fertilization in B.C. was viewed as an enhancement technique, with the benefit/cost ratio of any given project being a major factor in deciding feasibility and success or failure. The new paradigm of anthropogenically induced oligotrophication has altered how lake fertilization is perceived. It is now also viewed as a restoration technique that can be used to bring lake ecosystems and their sockeye stocks closer to past levels of productivity. Further, new policies and initiatives such as DFO's Strategic Plan, the Wild Salmon Policy, and the Pacific Salmon Review are bringing a heightened emphasis on conservation, which will have a major effect on how lake fertilization projects are prioritized, selected, and assessed. With restoration of weak stocks as a major goal, fertilization projects on oligotrophic lakes with depressed sockeye stocks and consequently low benefit/cost ratios become feasible. An example of this is the 1997 Adams Lake restoration project, where despite a low short-term benefit/cost ratio, fertilization was used in conjunction with fry outplants to successfully enhance this depressed stock (J. Hume, unpublished data). Further examples are sockeye nursery lakes which are located in parks (e.g. Chilko, Chilliwack, Hobiton). In the past, nutrient additions were regarded by Parks Canada, provincial authorities, and some stakeholders as an undesirable modification to the natural environment, so nutrient additions to lakes within parks were not acceptable. Such organizations and people are now coming to understand that these lakes have undergone harmful habitat alterations (through loss of carcass nutrients) and are currently in a degraded state. It is also now understood that fertilization with inorganic nutrients can be a successful surrogate for these lost salmon carcass nutrients.

The Wild Salmon Policy currently being developed by Fisheries and Oceans Canada will affect management and enhancement activities throughout the Pacific Region. Principle One of the policy states that "the preservation of the quality, diversity, and productive capacity of salmon habitat, and its accessibility to salmon, should be the primary consideration of any strategy to conserve wild Pacific salmon". The productive capacity of most B.C. sockeye nursery lakes has been, and continues to be, degraded because a substantial proportion of returning adults are harvested in various fisheries and thus prevented from contributing their nutrients to their natal streams and lakes. Lake fertilization is the only available technique to ameliorate this nutrient loss, which will continue as long as stock sizes are reduced and/or a substantial fishery is present. In discussing Fraser system sockeye stocks Ricker (1987) stated, "We would not, of course, want to have on any spawning ground as many sockeye as in the old big years. Theory and observation both indicate that maximum sustainable yields will be obtained when spawners are one-quarter to one-third as numerous as their unfished abundance, certainly less than half. And to support the young from even these levels of spawning the lakes will almost certainly require artificial fertilization to replace their former enrichment by 100,000 tons or so of dead sockeye every fourth year."

Since sockeye stock size can be constrained by a variety of factors, appropriate method(s) of increasing sockeye numbers can only be selected if limiting factors for each lake are understood. These limiting factors can be grouped into mechanisms resulting in either poor recruitment or in decreased survival. An obvious cause of small stock size is low spring fry recruitment, which can be the result of low spawner numbers, low spawning ground capacity, and/or poor egg-to-fry survival. Depending on the mechanism, low recruitment can be increased by decreasing harvest rates, by improving spawning grounds (e.g. removal of beaver dams or construction of spawning channels), or by direct methods such as fry outplants. Juvenile stock size is also affected by survival which in turn is indirectly affected by growth. Survival and growth of sockeye during their lake residence may be poor if sockeye fry densities are high enough, or if lake productivity is so low that the zooplankton food supply is inadequate regardless of planktivore numbers. In either of these cases, if a lake's physical and chemical environment is suitable, productive capacity may be increased, with concomitant increases in sockeye growth and survival, through lake fertilization. Sockeye growth and survival may also be adversely affected if there is substantial competition with other limnetic planktivores (e.g. smelt, stickleback, mysids), or if the lake's physical environment is unfavorable (e.g. high temperatures and/or low oxygen). In some situations, high predator numbers may cause substantial reductions in juvenile sockeye numbers. The feasibility of reducing competition or predation or of improving the physical environment depends on the specific factors affecting sockeye in an individual lake but predator reduction has successfully increased sockeye numbers in some cases (Foerster and Ricker 1941; Rieman and Beamesderfer 1990).

In this report we present summaries of data collected from 60 B.C. sockeye nursery lakes between 1977 and 2000. The amount of sampling on individual lakes varied considerably, from a single limnological sampling date on some lakes, to multiple years of intensive studies of a lake's limnology and limnetic fish communities on others. Some of the data presented have been presented elsewhere, but they have not been presented in a cohesive and uniform format with the specific objective of assessing restoration and enhancement opportunities. We list factors which constrain sockeye production in each lake and, where possible, make recommendations on the technique(s) most likely to increase stock size. Whole-lake fertilization projects were carried out on a number of the lakes in some years. Where possible, we discuss the effects of fertilizer applications on these lakes. Funding for these investigations came from a variety of sources, with the most prominent being the Salmonid Enhancement Program, Pacific Salmon Treaty, and Skeena Green Plan.

I. B.C. sockeye nursery lakes

Sockeye nursery lakes occur in all regions of B.C., with the exception of the Peace River drainage basin in northeastern B.C. (east of the Cassiar mountains), and parts of the Columbia River drainage basin in southeastern B.C. The lakes are situated in most of the province's varied climatic and geologic regions, with correspondingly large variations in latitude and elevation (Table 1). Some of the lakes occur almost at sea level, while elevation of others exceeds 1,200 m. B.C. nursery lakes occur over a north-south range of >1000 km. This large variation in climate, geology, latitude and elevation results in wide differences in thermal regimes, water clarity, water residence times, nutrient loading, and trophic status. Nursery lake surface area ranges more than two orders of magnitude, from <2 km^2 to >400 km^2. Mean depths range from <6 m to >150 m and water residence times range from several days to >20 yr. Trophic status ranges from ultra-oligotrophic to meso-eutrophic. Some nursery lakes have high water clarity while others are turbid from either glacial or organic inputs. Distances from the ocean range from <1 km to >1000 km.

Total surface area of B.C.'s more than 90 sockeye nursery lakes is approximately 3,800 km^2. The 60 lakes in this report comprise almost two-thirds of B.C.'s sockeye lakes, but make up 90% of the surface area of B.C. sockeye lakes. In addition, there are many lakes which for various reasons do not currently have a sockeye population but do have substantial underutilized rearing capacity. Size of stocks in B.C. sockeye lakes is highly variable. In some years adult returns to major producers such as Quesnel or Shuswap lakes have exceeded 10 million, with spawning escapements of 1-2 million. Returns to some smaller lakes or to major producers in non-dominant brood years have been as low as a few individuals to a few thousand fish. The nursery lakes contain over 590 spawning streams, of which over half have fewer than 1,000 spawners, while about 4% of the streams have peak spawning populations in excess of 100,000 (Williams and Brown 1994). The Fraser River system has nine lakes where escapements have exceeded 100,000 in recent years (Chilko, Fraser, Harrison, Lillooet, Quesnel, Shuswap, Stuart, Takla, and Trembleur). Of northern B.C. stocks, only Babine Lake on the Skeena River and Meziadin Lake on the Nass River have had recent escapements exceeding 100,000. Of coastal B.C. lakes, five (Great Central, Long, Nimpkish, Owikeno, and Sproat) have had escapements that exceeded 100,000, although in recent years escapements to Long, Nimpkish, and Owikeno lakes have been far lower.

II. Methods

We obtained lake morphometric parameters from several sources, including Canadian Hydrographic charts, 1:50,000 topographic maps, Pacific Salmon Commission bathymetric maps, and the British Columbia Ministry of Fisheries, B.C. Lake Survey Database. Over the 22 years that these data were collected, some methods and instrumentation changed. Detailed descriptions of methods and instruments used on specific dates and lakes can be found in a number of different publications (see reference list). Sampling frequency for each lake ranged from a single sampling date to twice monthly over the growing season for several years. Number of locations sampled on each lake varied from one to six, depending on the lake's size and complexity. Where possible, data presented in this report are whole-lake, growing season averages. Seasonal averages are time-weighted means of data obtained during the growing season. In larger lakes where more than a single location was sampled, whole-lake averages are weighted by the lake area represented by each sampling location. On those lakes where time series permit ($n \geq 3$), annual variability in the whole-lake averages is expressed by 2 standard errors (% ±2SE).

Temperature and conductivity profiles were collected with a variety of instruments, ranging from a mechanical bathythermograph in earlier years, to *in-situ* digital conductivity, temperature, and depth meters from the mid-1980's to the present. We calculated vertical light extinction coefficients using light data (photosynthetically active radiation: 400-700 nm) collected from the surface to below the euphotic zone depth (1% of surface intensity) with Li-COR light meters and underwater quantum sensors. We measured water transparency with a 22-cm white Secchi disk.

All water samples were collected with a sterilized Van Dorn Bottle. Several (three to seven) epilimnetic depths and from one to three hypolimnetic depths were sampled at each station. Total alkalinity and pH were determined according to the potentiometric method of APHA (1980). Dissolved inorganic carbon (DIC) was either determined with a gas chromatograph (Stainton et al. 1977) or was calculated indirectly from pH, temperature, total dissolved solids and bicarbonate alkalinity. Chemical analyses were carried out according to methods given in McQuaker (1973), Stainton et al. (1977), and Stephens and Brandstaetter (1983).

Chlorophyll samples were analyzed using Golterman's (1969) method and concentrations were calculated according to Strickland and Parsons (1972). Photosynthetic rates (PR) were estimated using the ^{14}C-uptake method and *in-situ* incubations (Shortreed et al. 1998).

Zooplankton samples were collected with vertical hauls using either a Wisconsin (mouth area=0.05 m^2, 160-µm mesh) or a SCOR net (mouth area=0.25 m^2, 100-µm mesh). In earlier studies, biomass (dry weight) of the sample was measured directly (Rankin et al. 1983). This method provided an estimate of total zooplankton biomass, but did not provide species-specific biomass data. Since 1984, we have identified zooplankton to genus and measured body length with a computerized measuring system (MacLellan et. al. 1993). We then calculated species-specific and total macrozooplankton (body length >250µm) biomass from published length-weight regressions for each genus.

Limnetic fish population estimates were obtained with either a Biosonics 105 dual-beam or a Simrad EY-M single-beam hydroacoustic system (Shortreed et al. 1998; Hyatt et al. 2000). In lakes inaccessible by road and in many coastal lakes, the Simrad system was used and numbers of limnetic fish were calculated with an echo counting method modified from Hyatt et al. (1984). Samples of limnetic fish were collected from these lakes with a 2x2 m midwater trawl (Gjernes 1979). In lakes that were accessible by road, the Biosonics dual-beam system was used and population estimates were determined through echo integration (Burczynski and Johnson 1986). Samples of the limnetic fish community, collected from these lakes with a 3x7 m midwater trawl (Enzenhofer and Hume 1989), were used to determine species and age composition as well as size of juvenile sockeye. Frequency of limnetic fish sampling ranged from a single survey to three surveys per year over several years. In some lakes in recent years, juvenile sockeye and kokanee were differentiated through either electrophoretic analysis (Wood and Foote 1990) or analysis of Sr/Ca ratios in the primordia of the otolith (Kalish 1990, Rieman et al. 1994, Volk et al. 2000).

The methodology and quality of sockeye spawning escapement estimates vary greatly throughout the province. Three main spawner estimation techniques are used: mark-recapture, enumeration fences, and visual counts (on foot or by air) of live and/or dead spawners. Estimates of spawner numbers for many of the smaller and more remote stocks are done in a cursory fashion. Data and methods for the Fraser River watershed are presented in Schubert (1998, and references therein), for Babine Lake in Wood et al. (1998), for other Skeena River lakes in McKinnell and Rutherford (1994), and for Owikeno and Long lakes in Rutherford and Wood (2000b). Methods for other systems have not been reported in published documents, but some are available in DFO's "Annual Reports of Salmon Streams and Spawning Populations". Data from these reports were originally stored in the Salmon Escapement Database System (SEDS, Serbic 1991) and are now available on the DFO Intranet in an updated version of SEDS named NuSEDS V1.0 (http://sci.info.pac.dfo.ca/sein_prod/Default.htm). Few estimates of spawning ground capacity have been made for B.C. lakes or streams. Rough estimates of a number of Skeena-system lakes were made by Brett (1952) in the late 1940's and have not been revised since. Capacity of some Babine Lake spawning areas (Fulton and Pinkut Creeks and their associated spawning channels) were reported by West 1987. Rosberg et al. (1986) estimated spawning channel capacity for the channels built by the International Pacific Salmon Fisheries Commission in the Fraser River system.

An important factor in assessing the need or potential for restoration and enhancement of a lake's sockeye stocks is determining what proportion of a lake's productive capacity is currently being utilized. To address this and other questions relevant to freshwater rearing capacity of sockeye lakes, we developed a sockeye rearing model (the PR model) which is based on relationships between seasonal average photosynthetic rate (PR_{mean}) and juvenile sockeye production (Hume et al. 1996; Shortreed et al. 1999). The PR model provides predictions on the numbers of adult spawners required to fully utilize a lake's rearing capacity, the maximum biomass of smolts a lake can produce, and how these factors will change if the lake's productivity is increased (e.g. fertilization). Where appropriate data are available in this report, we provide PR model predictions of optimum escapement for each lake and compare these to recent escapements. Model predictions presented in this report are unadjusted, and may overestimate optimum escapements in lakes which have substantial numbers of planktivores other than age-0 sockeye (including age-1 sockeye), or in lakes which are shallow. Assumptions and limitations of the PR model are discussed at length in Shortreed et al. (1999).

III. Results and Discussion

Provided below is a summary of current knowledge of each lake and factors constraining productivity of each lake and its sockeye stocks. Where possible, appropriate enhancement or restoration techniques are suggested. Lakes are located in five of DFO's management areas and are grouped accordingly.

B.C. Interior

Adams Lake

Adams Lake is large (surface area=129 km²) and deep (mean depth=169 m). It is located approximately 60 km northeast of Kamloops and is drained by the Adams River, which enters Shuswap Lake near its outlet. We collected limnological data in 1986, 1997, and 1998 (Nidle et al. 1990; K. Morton, unpublished data). Limnetic fish data were collected from 1975-1978 and from 1997-1998, inclusive (Mueller and Enzenhofer 1991; J. Hume, unpublished data). At the time of sampling, Adams Lake provided a good physical environment for juvenile sockeye with a stable thermocline (seasonal mean depth=7.5 m), an average epilimnetic temperature of 14.6°C, a deep, cool hypolimnion, and clear water (mean euphotic zone depth=13.3 m) (Table 2). However, in some years summer epilimnetic temperatures exceeded 20°C for sustained periods and juvenile sockeye most likely had reduced access to the epilimnetic plankton community. Nitrogen loading was relatively high, with nitrate concentrations of 101 μg N/L at spring overturn and seasonal minimum epilimnetic nitrate of 18 μg N/L in late summer (Table 3). The lake exhibited a high degree of phosphorus limitation, with spring overturn total phosphorus concentrations averaging only 1.6 μg/L. Adams Lake was strongly oligotrophic with an average chlorophyll concentration of 0.81 μg/L and a seasonal average photosynthetic rate (PR_{mean}) of 111 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). Macrozooplankton and *Daphnia* biomass were relatively high given the lake's oligotrophic status, most likely because of the very low planktivore numbers. Returns of Adams Lake sockeye have been very small (from less than a hundred to a few thousand) for most of this century. Historical accounts (Williams

1987) indicate that prior to 1910 the lake supported substantial numbers of sockeye. Two stocks (an early and a late run) make up the majority of Adams Lake sockeye. Most late run sockeye return in the same cycle year (1998) as the dominant sockeye return to Shuswap Lake and estimates of late run escapement numbers are available for only ten of the last 60 yr. Until recently, and with the exception of 1942, when the escapement estimate was 200,000, spawner numbers have not exceeded 7,200. Almost all early run sockeye return in the 1996 cycle year and have been the target of extensive rebuilding efforts (Williams 1987; J. Hume, unpublished data). As a result of these efforts, the stock has increased from a few hundred fish in the 1950's to more than 70,000 spawners in 2000 (Table 6). In an effort to accelerate this long-term restoration, the lake was fertilized in 1997 in conjunction with fry outplants. Fertilization increased lake productivity, zooplankton biomass, and sockeye growth rates. During the fertilized 1997 brood year, juvenile sockeye diet was comprised almost entirely of *Daphnia*. Average smolt size from the unfertilized 1992 brood year was 2.6 g and was 3.5 g from the fertilized 1997 brood year, which was a substantial (38%) and significant ($F=90.0$, $p<0.001$) increase (Table 5). For continued rebuilding of Adams Lake sockeye, a continuation of both fertilizer additions and fry outplants in the dominant brood year are recommended (Table 7).

Anderson Lake

Anderson Lake is a fiord-like lake located in a semi-arid area west of the town of Lillooet. It drains via Portage Creek into Seton Lake, has a surface area of 28 km² (Table 1), and a mean depth of 140 m (Table 2). The major sockeye spawning area for this lake is the Gates Creek spawning channel, located on Gates Creek, which drains into the upper end of Anderson Lake. Data collected in the 1950's suggests that a variable but occasionally substantial proportion of fry from Gates Creek migrate through Anderson Lake and rear in Seton Lake (Geen and Andrew 1961). We collected limnological data from Anderson Lake on six occasions from May to October of 2000 and carried out an acoustic survey in September of that year. Trawl surveys were carried out in the 1970's, 1980's, and in 2000 (n=4). Anderson Lake had a relatively deep (18.2 m) epilimnion and was very clear, with an average euphotic zone depth of 22.6 m (Table 2). Mean epilimnetic temperature was 14.2°C and the maximum recorded surface temperature of 18.5°C occurred in mid-August. Overall, the lake had an excellent physical environment for juvenile sockeye. The lake was slightly alkaline, with an average pH of 7.49, and had a relatively high total alkalinity of 46.0 mg $CaCO_3$/L (Table 2). Nitrate concentrations were 50 µg N/L at spring overturn and epilimnetic concentrations declined to 4.5 µg N/L in late summer (Table 3). The spring overturn total phosphorus concentration of 4.7 µg/L puts the lake in the mid-range of oligotrophy. The relatively high PR_{mean} of 276 mg $C\cdot m^{-2}\cdot d^{-1}$ and the relatively low average chlorophyll concentration of 1.04 µg/L indicates a phytoplankton community with rapid turnover and high loss rates (Table 4). This was explained by elevated grazing pressure from the unusually high macrozooplankton biomass of 2,622 mg dry wt/m² (the highest of any Fraser system sockeye lake for which data are available), of which 40% was *Daphnia* (Table 4). In 2000, fall density of *O. nerka* was 1,057/ha and fry were small, averaging only 1.1 g, much smaller than expected given the high plankton biomass. However, Sr/Ca ratios in the otoliths indicate that >95% of these fish were kokanee. These data support the earlier work (Geen and Andrew 1961) which concluded that most Gates Creek fry rear in Seton Lake.

The PR model predicts that optimum escapement to the lake is 260,000, considerably more than the average escapement to both Seton and Anderson lakes of 41,000 spawners (maximum recorded escapement is 104,000) (Table 6). This is a strong indication that Anderson is a productive lake with substantially underutilized rearing capacity. Limnological conditions indicate that lake fertilization would be of little benefit at current spawner densities and that increased fry recruitment to Anderson Lake would result in increased smolt production. However, the freshwater behaviour of Gates sockeye fry (i.e. what proportion rear in Anderson Lake and what proportion migrate into Seton Lake) needs to be better understood before any additional enhancement is undertaken (Table 7). Earlier work suggested that the majority of Gates fry rear in Seton Lake, and that fry rearing in Seton Lake have higher growth rates than fry rearing in Anderson Lake (Geen and Andrew 1961). This occurred despite much lower planktivore densities and much higher plankton biomass in Anderson Lake. This apparent anomaly needs to be verified before projects to more fully utilize Anderson Lake's rearing capacity are undertaken.

Bonaparte Lake

Bonaparte Lake is located approximately 80 km north of Kamloops and is drained by the Bonaparte River, which enters the Thompson River near Ashcroft. Until the early 1990's, Bonaparte Lake was not accessible to anadromous fish. In 1990-1992, fishways were constructed at a set of falls 2 km upstream of the confluence of the Bonaparte and Thompson rivers and at a dam at the outlet of Bonaparte Lake. To date, no sockeye have been observed migrating through the fishways (H. Stalberg, Fisheries and Oceans Canada, personal communication). We collected limnological data from Bonaparte Lake three times (May, August, and October) in 1992. Limnetic fish data were collected in the fall of the same year. Bonaparte Lake has a surface area of 34 km² and a mean depth of 40 m (Table 1). On the two dates sampled when the lake was stratified (August and October), average thermocline depth was 14.8 m and the euphotic zone depth averaged 13.3 m (Table 2). Average epilimnetic temperature was 10.4°C. These data indicate that Bonaparte Lake has a physical environment that is favorable to juvenile sockeye. Spring overturn total phosphorus concentrations averaged 6.4 µg/L, indicating the lake was in the middle to upper range of oligotrophy (Table 3). However, nitrate concentrations were extremely low, with spring overturn concentrations of only 1.9 µg N/L. In summer and fall, both epilimnetic and hypolimnetic nitrate concentrations were <2 µg N/L. A system this depauperate in nitrogen is highly unusual, and leads to the tentative conclusion that productivity could be increased, and plankton community composition improved, by the addition of nitrogen fertilizer alone. The average chlorophyll concentration of 1.22 µg/L and the PR_{mean} of 131 mg $C \cdot m^{-2} \cdot d^{-1}$ also indicate the lake was in the middle range of oligotrophy (Table 4). Average macrozooplankton biomass was 816 mg dry wt/m², of which 37% was *Daphnia*. If data had been collected more frequently during the growing season, these averages would likely have been substantially higher.

Kokanee density in the fall of 1992 was 120/ha and their average size was 3.2 g, which is large for age-0 kokanee in most B.C. lakes (Table 5). Bonaparte Lake would provide an excellent rearing environment for juvenile sockeye and the PR model suggests that at its current productive capacity it could sustain fry from approximately 150,000 adult spawners. Its productivity is limited by nutrient availability (primarily nitrogen), so fertilization would be a viable option once fry recruitment is at high enough levels (Table 7). Although questions such as the quantity and quality of potential spawning ground capacity and the effect of additional planktivores on resident fish stocks need to be answered, fry outplants from a suitable donor stock might be sufficient to establish a self-sustaining sockeye population in Bonaparte Lake.

Bowron Lake

We carried out a limnological survey of Bowron Lake on only one occasion in early October of 1981 (Stockner and Shortreed 1983). Bowron Lake is located 100 km east of the town of Quesnel in Bowron Lake Provincial Park. It is relatively small (surface area=10.0 km²) and shallow (mean depth=16 m) (Table 1). At the time of our survey the lake was weakly stratified, had a deep (24.5 m) thermocline, a cool surface temperature of 9.2°C, and a euphotic zone depth of 10.4 m (Table 2). While spring overturn data are not available, hypolimnetic total phosphorus concentration was 4.0 µg/L, and hypolimnetic nitrate was substantially higher (90 µg N/L) (Table 3). At 1.51 µg/L, chlorophyll concentration in early October was higher than seasonal average chlorophyll in most Fraser system nursery lakes (Table 4). Given the weak stratification and cool temperatures, the zooplankton biomass of 646 mg dry wt/m² on the date sampled was likely less than the lake's seasonal average plankton biomass. No limnetic fish data are available for Bowron Lake. In the last 10 yr, sockeye escapement has averaged 8,700 (8.7/ha) and ranged from 1200-34,000 (1.2-34.4/ha). These are lower spawner densities than is seen in most of the major Fraser system sockeye nursery lakes. The limited data suggest that sockeye production from Bowron Lake is recruitment-limited in most years. They also suggest that the lake's productive capacity could be increased with fertilizer additions. However, more detailed limnological and limnetic fish data must be collected before any specific method of restoring abundance of Bowron sockeye could be recommended (Table 7).

Chilko Lake

Chilko Lake is located 180 km southwest of Williams Lake within Ts'yl-os Provincial Park. Limnological data were collected either monthly or twice monthly (May to October) from 1984-1986 and from 1988-1995 (Hume et al.1996; Shortreed et al. 1999; Bradford et al. 2000). A smolt enumeration program has been carried out annually from 1950 to the present. The lake was fertilized in 1988 and from 1990-1993, inclusive. Chilko is a large lake (surface area=185 km²) and during our study, provided an excellent physical habitat for juvenile sockeye with a cool (mean temperature=8.2°C), deep (mean depth=24.2 m) epilimnion, and an extensive hypolimnion (Tables 1 and 2). With an average seasonal euphotic zone depth of 20.9 m (n=5, ±2SE=17%), Chilko was the clearest sockeye nursery lake in the Fraser system. Nutrient loading was very low, with average spring overturn total phosphorus concentrations of only 1.9 µg/L (n=6, ±2SE=31%)and spring overturn nitrate of 21 µg N/L (n=6, ±2SE=21%) (Table 3). As a result, the lake was ultra-oligotrophic, with a PR_{mean} of only 82 mg $C \cdot m^{-2} \cdot d^{-1}$ (n=4, ±2SE=5%) (Stockner and Shortreed 1994; Table 4). *Daphnia* biomass was low, and juvenile sockeye fed primarily on *Diacyclops* and *Bosmina*. Macrozooplankton biomass declined rapidly with increasing fry density. Chilko Lake responded positively to fertilizer additions, with increases in phytoplankton production, zooplankton biomass (including substantial increases in *Daphnia* numbers), smolt size, freshwater survival (at higher fish densities), and adult returns (Bradford et al. 2000). Until the late 1980's, Chilko sockeye had three large and one small non-dominant return in each 4-yr cycle. Since that time, Chilko has had large escapements in every cycle year. Since 1996, annual escapements have been approximately one million, considerably higher than the optimum escapement of 513,000 spawners (Table 6). These high escapements have resulted in fewer numbers of smaller smolts than the lake produces when escapements are at optimum levels. During fertilized years, equivalent high spawner numbers produced substantially greater numbers of smolts. Given the new emphasis on a precautionary approach to exploitation rates, it is unlikely that Chilko escapements will be reduced to optimum levels. To reverse this downward trend in smolt numbers, fertilizer applications should be resumed (Table 7).

East Barriere Lake

In 1988, we collected monthly (May to October) limnological data from East Barriere Lake and collected limnetic fish data in summer and fall of the same year. The lake has a surface area of 9.9 km², a mean depth of 48 m, and is located 80 km northeast of Kamloops (Table 1). During the sampling period, average epilimnetic temperature was 13.7°C and the lake had a shallow (mean=6.0 m), stable seasonal thermocline (Table 2). The euphotic zone depth averaged 7.8 m, slightly greater than the average depth of the seasonal thermocline. Spring overturn phosphorus concentration was 8.6 µg/L, placing East Barriere Lake in the upper range of oligotrophy (Table 3). Nitrate concentration was relatively low (16 µg N/L) at spring overturn and by late summer epilimnetic nitrate was only 4.8 µg N/L. The average chlorophyll concentration of 1.49 µg/L was commensurate with the observed nutrient concentrations (Table 4). Macrozooplankton biomass averaged 307 mg dry wt/m² and *Daphnia* made up 55% of this total. Difficult fish passage in the Barriere River reportedly prevents upstream passage by adult sockeye (T. Panko, Fisheries and Oceans Canada, personal communication) so sockeye fry do not utilize the lake. The lake did, however, support a relatively abundant kokanee population (age-0 density in fall was 400/ha) with an average fall fry size of 2.0 g. The data indicate that East Barriere Lake could support substantially more limnetic fish than it does at present. However, further work is required to determine how much of lake's productive capacity is underutilized. If fish passage difficulties can be resolved and questions such as the quantity and quality of potential spawning grounds and the effect of additional planktivores on resident fish stocks answered, fry outplants from a suitable donor stock may be sufficient to establish a self-sustaining sockeye population in East Barriere Lake (Table 7).

Francois Lake

Limnological data from Francois Lake were collected once monthly from May to October of 1992 and 1993 and limnetic fish data were collected on five occasions from 1975-1992 (Shortreed et al. 1996). Francois is a large (surface area=250 km²) and deep (mean depth=87 m) sockeye nursery lake located 25 km south of the town of Burns Lake (Table 1). At the time of sampling, it provided an excellent physical habitat for sockeye fry, with a cool epilimnion (mean epilimnetic temperature=13.3°C), a 10.9 m euphotic zone, and an average thermocline depth of 17.2 m (Table 2). The lake was in the upper range of oligotrophy and had nutrient loading and production rates (PR_{mean}=163 mg $C \cdot m^{-2} \cdot d^{-1}$) similar to those found in Shuswap Lake (Tables 3 and 4). During our study, *Daphnia* were abundant and juvenile sockeye stomachs averaged 70% full, with *Daphnia* comprising >90% of their diet. Limnetic fish densities were low and the average size of age-0 fry in September was 5.2 g (Table 5). The average escapement of 37,000 is far below the predicted optimum of nearly 1.4 million (Table 6). The PR model estimate of lake rearing capacity is 27 times greater than estimated spawning ground capacity. Therefore, increasing fry recruitment through increased escapements combined with expanding spawning ground capacity would be the most effective enhancement strategy in Francois Lake (Table 7). Francois Lake's large size, high productivity, and *Daphnia*-dominated plankton community mean it has the potential to be one of the major sockeye producers in B.C.

Fraser Lake

Fraser Lake is located 50 km west of Vanderhoof, has a surface area of 54 km², and is relatively shallow, with a mean depth of 13 m (Table 1). Limnological data from Fraser Lake were collected once monthly from May to October of 1992 and 1993 while limnetic fish data were collected on ten occasions from 1975-1993 (Shortreed et al. 1996). During sampling, it was thermally stratified for an extended period of the growing season (mean epilimnetic temperature=15.3°C; average thermocline depth=10.6 m), providing a cold water refuge area for juvenile sockeye (Table 2). These characteristics provide a good physical habitat for sockeye fry. The lake was close to eutrophic (spring overturn total phosphorus concentrations averaged 17.8 µg/L) and had the highest PR_{mean} (332 mg $C\cdot m^{-2}\cdot d^{-1}$) yet recorded for a B.C. sockeye nursery lake (Tables 3 and 4). It had low nitrogen loading (spring overturn nitrate concentrations average only 3.0 µg N/L), with the result that nitrate was depleted for much of the growing season. The high P load, low N load, and stable thermal stratification occasionally resulted in summer blooms of nitrogen-fixing cyanobacteria. The lake had an abundant zooplankton community (*Daphnia* biomass was the highest yet recorded for a Fraser system sockeye nursery lake) and fall sockeye fry were large (mean=4.5 g) (Table 5). At current escapement levels (average escapement=163,000) the lake's rearing capacity is considerably under-utilized (Table 6). The maximum recorded escapement of 372,000 is substantially less than the PR model predicted optimum of 601,000. Increasing abundance of Fraser Lake sockeye could be accomplished solely by increasing fry recruitment (Table 7). If human activity in the drainage basin continues to increase, it would be advisable to monitor nutrient loading and oxygen concentrations in the lake.

Momich Lake

Momich Lake is located 100 km northeast of Kamloops and drains via the Momich River into the upper portion of Adams Lake. We carried out a limnological survey of Momich Lake on one occasion in early October of 1981 (Stockner and Shortreed 1983). Momich Lake is small (surface area=2.0 km²) and has a mean depth of 32 m (Table 1). At the time of our survey, the surface temperature was 10.9°C and the euphotic zone was 6.9 m deep (Table 2). While spring overturn data are not available, hypolimnetic total phosphorus concentration was 3.5 µg/L and hypolimnetic nitrate was 52 µg N/L, suggesting strong P-limitation. Chlorophyll concentration in early October was 2.13 µg/L, higher than seasonal average chlorophyll found in most Fraser system nursery lakes. Zooplankton biomass was 412 mg dry wt/m² which was likely less than the seasonal average, given the late season sampling date and the lake's relatively weak stratification and cool temperature (Table 4). No limnetic fish data are available for Momich Lake. Sockeye escapements to tributaries upstream of Momich Lake (Cayenne Creek and the Upper Momich River) have been increasing for some time. In the last dominant brood year (1997), 9,400 sockeye spawned upstream of Momich Lake (Table 6). It is unknown what proportion of fry from these areas rear in Momich Lake and how many rear downstream in nearby Adams Lake. However, if all progeny from these 9,400 spawners reared in Momich Lake, then the lake would have been at or near its rearing capacity. The limited data suggest that sockeye production from Momich Lake is recruitment-limited in all but dominant brood years. They also indicate that the lake's productive capacity could be increased with fertilizer additions, since it appears to be strongly P-limited. However, more detailed limnological and limnetic fish data must be collected before any particular method of increasing the abundance of Momich sockeye could be recommended (Table 7).

North Barriere Lake

In 1988 we collected monthly (May to October) limnological data and collected limnetic fish data in summer and fall of the same year. North Barriere Lake is small (surface area=5.2 km²), has a mean depth of 35 m, and is located 80 km northeast of Kamloops (Table 1). During the study, the lake had an average epilimnetic temperature of 12.3°C and a shallow (mean=5.8 m), stable seasonal thermocline (Table 2). The euphotic zone depth averaged 7.4 m, slightly greater than the average depth of the seasonal thermocline. Spring overturn phosphorus concentration was 5.7 µg/L, placing the lake in the middle to upper range of oligotrophy (Table 3). Nitrate concentration was low (21 µg N/L) at spring overturn and by late summer epilimnetic nitrate was depleted (<1 µg N/L). The average chlorophyll concentration of 5.0 µg/L was the highest yet recorded for a B.C. sockeye nursery lake and was higher than expected, given the observed nutrient concentrations. Macrozooplankton biomass was the lowest (191 mg dry wt/m²) yet recorded for a Fraser system sockeye nursery lake. Average escapement is 12,000 (Table 6). A high escapement in 1987 resulted in a relatively high spawner density of 33/ha of lake surface area, and a 1988 fall age-0 sockeye density of 3,600/ha (Table 5). An unknown but probably minor proportion of these were kokanee. Despite these high densities, average size of sockeye fry in the fall of 1988 was 2.9 g. The high limnetic fish density was likely responsible for the low macrozooplankton and *Daphnia* densities and suggest the lake's rearing capacity has been reached or exceeded. In turn, the low herbivorous plankton density likely explains the higher than expected chlorophyll concentrations.

North Barriere Lake is the only recorded sockeye nursery lake on the North Thompson River. Sockeye returns to Fennell Creek, the major spawning tributary into North Barriere Lake, have been increasing since the early 1960's, with the highest historical escapement of 33 thousand spawners (64 /ha) occurring in 1996 (Table 6). If all progeny from these spawners rear in North Barriere Lake, it is probable that spring fry recruitment is already at or in excess of optimum. Further work is needed to determine the lake's productive capacity and the escapement levels that will maximize sockeye production (Table 7). Available data suggest that lake fertilization would be of benefit at high spawner densities.

Quesnel Lake

Limnological data from Quesnel Lake were collected from May to October (n=6 in each year) from 1985-1988, in 1990, and in 1994 (MacLellan et al. 1993; Nidle et al. 1994). Limnetic fish data were collected monthly (May to October) in 1990, in the summer and fall of 1986-1989, 1991-1992, 1994-1995, and in the fall of 1989, 1993, and 1998 (Morton and Williams 1990; Hume et al. 1994, 1996; J. Hume, unpublished data). Quesnel Lake is a large (surface area=270 km²), deep (mean depth=158 m) lake located 100 km southeast of the town of Quesnel (Table 1). At the time of sampling, it provided an excellent physical environment for juvenile sockeye with a mean thermocline depth of 12.4 m, a mean epilimnetic temperature of 12.4°C, and a 15.5 m (n=6, ±2SE=6%) average euphotic zone depth (Table 2). The lake had an average spring overturn total phosphorus concentration of 2.7 µg/L (n=6, ±2SE=14%), and a seasonal average chlorophyll concentration of 1.03 µg/L (n=6, ±2SE=7%), which places it in the lower range of oligotrophy (Tables 3 and 4). In addition, phytoplankton productivity was low (PR_{mean}=102 mg $C \cdot m^{-2} \cdot d^{-1}$, n=5, ±2SE=11%) relative to other interior Fraser lakes. Since the lake had an abundant nitrogen supply (spring overturn nitrate concentration was 104 µg N/L, n=6, ±2SE=20%) production was likely P-limited.

Sockeye returns to the lake are highly cyclic and since 1985, escapements in dominant years have exceeded the predicted optimum escapement of 931,000 (Table 6). Subdominant escapements have been increasing steadily and in 1998 exceeded the optimum for the first time in recent history. *Daphnia* was abundant during years of lower fry density but during years of high fry density its abundance declined to levels where sockeye diet shifted to less efficient prey items. Growth and survival rates of sockeye fry were strongly density-dependent in years when fry were abundant. Fall fry size ranged from 2.7 g in high density years to 9.4 g during years of low fry density (Table 5). Quesnel Lake is an excellent candidate for fertilization during dominant and subdominant brood years. Fertilization of Quesnel Lake has the potential to produce several million additional adult sockeye returns in each dominant and subdominant brood year (Stockner et al. 1994).

Seton Lake

Seton Lake is located in a semi-arid area west of the town of Lillooet. It drains via Seton Creek into the Fraser River near Lillooet. Fry recruiting to Seton Lake are from spawning areas in Portage Creek (which links Anderson and Seton lakes) and from Gates Creek spawning channel. Data collected in the 1950's indicated that a variable but occasionally substantial proportion of fry from Gates Creek migrate through Anderson Lake to rear in Seton Lake (Geen and Andrew 1961). Originally, Anderson Lake (via Portage Creek) formed the major inflow to Seton Lake. Starting in 1934, a relatively small amount of Bridge River water was diverted into Seton Lake. This diversion (for power generation) of water from the more turbid Bridge River (now called Carpenter reservoir) has been expanded several times and since 1961 inputs substantially more water to Seton Lake than does Portage Creek. Portage Creek now contributes approximately one-third of the water entering Seton Lake. We collected limnological data from Seton Lake on six occasions from May to October of 2000 and carried out an acoustic survey in September of that same year. Trawl surveys were carried out in the 1970's, 1980's, and in 2000 (n=5). Seton Lake has a surface area of 24 km^2 and a mean depth of 85 m (Table 1). With a relatively deep thermocline (22.4 m) and a cool average epilimnetic temperature (13.5ºC), the lake's physical environment was highly suitable for sockeye rearing. The lake's average euphotic zone depth of 11.2 m was one-half that of Anderson Lake (Table 2). This was due primarily to the influence of turbid water from Carpenter reservoir. The lake was slightly alkaline, with an average pH of 7.30 and a total alkalinity of 34.1 mg $CaCO_3$/L. Nitrate concentrations were 30 µg N/L at spring overturn and epilimnetic concentrations declined to 2.6 µg N/L in late summer (Table 3). The spring overturn total phosphorus concentration of 10 µg/L puts the lake in the mesotrophic category. PR_{mean} was high (219 mg $C \cdot m^{-2} \cdot d^{-1}$) and the average chlorophyll concentration was 1.49 µg/L (Table 4). The average zooplankton biomass of 422 mg dry wt/m^2 was lower than in many other Fraser system sockeye nursery lakes, but *Daphnia* made up 52% of this total. In 2000, fall density of *O. nerka* was 289/ha and fry were large, averaging 5.0 g, even though a substantial proportion of captured *O. nerka* were smaller kokanee (Table 5). Seton Lake is a productive lake with substantially underutilized rearing capacity. The PR model predicts that optimum escapement to the lake is 177,000, considerably more than the average escapement to both Anderson and Seton lakes of 41,000 spawners (maximum recorded escapement is 104,000) (Table 6). Limnological conditions indicate that lake fertilization would be of little benefit at current spawner densities and that increased fry recruitment to Seton Lake would result in increased smolt production. Increased fry recruitment would be best achieved by increasing spawning channel capacity and improving egg-to-fry survival within the existing facility. However, the freshwater behaviour of Gates Creek and channel sockeye fry (i.e. do they reside primarily in Anderson Lake or do they migrate into Seton Lake) needs to be resolved before any additional enhancement is undertaken (Table 7).

Shuswap Lake

Limnological data from Shuswap Lake were collected monthly (April to November) from 1987 to 1993 (Morton and Shortreed 1996; Hume et al. 1996; Nidle and Shortreed 1996). Limnetic fish data were collected on 34 occasions from 1987 to 1993 (MacLellan et al. 1995; Hume et al. 1996). Shuswap Lake is a large lake with surface area of 330 km^2 and a mean depth of 60 m (Table 1). During sampling, it provided a suitable, but less than ideal, physical environment for juvenile sockeye. Because of the mild, warm climate and generally calm conditions, the lake developed a strong, shallow (10 m) thermocline from May to October with epilimnetic temperatures exceeding 20ºC from early July to mid-September (Table 2). This may have had a negative effect on juvenile sockeye growth rates by restricting access to the epilimnetic plankton community, as suggested by Lebrasseur et al. (1978) for Great Central Lake sockeye. Shuswap Lake was in the mid-upper range of oligotrophy and had average spring overturn total phosphorus concentrations of 6.4 µg/L (n=7, ±2SE=16%) (Table 3). Spring overturn nitrate concentrations averaged 75 µg N/L (n=7, ±2SE=36%), but nitrate reached or approached depletion (<1 µg N/L) for a portion of each growing season. Photosynthetic rates in Shuswap Lake were higher (PR_{mean}=171 mg $C \cdot m^{-2} \cdot d^{-1}$, n=6, ±2SE=13%) than those in most other Fraser system sockeye lakes (Table 4). Macrozooplankton and *Daphnia* biomass were 1,005 mg dry wt/m² (n=7, ±2SE=14%) and 400 mg dry wt/m² (n=7, ±2SE=26%), respectively, which was consistent with lakes in the upper range of oligotrophy.

However, Shuswap Lake fry were substantially smaller (range=1.5-3.6 g) than those produced at similar densities in less productive lakes such as Chilko or Quesnel (Table 5). We suggest this is attributable to the warm epilimnion, which provided the zooplankton community with a summer refuge from predation. Compared to other lakes with more favorable physical environments, a smaller proportion of Shuswap Lake's plankton community was available for sockeye grazing. Sockeye returns to Shuswap Lake are strongly cyclic, with a large dominant return, a smaller subdominant return, and two small non-dominant returns in each 4-yr cycle. Dominant brood year escapements to Shuswap Lake in the 1980's and in 1990 (max=4 million) exceeded the PR model predicted optimum of 1,897,000 spawners. However, since 1990, both dominant and subdominant escapements declined and were substantially below this optimum (Table 6). While fertilization of the less productive arms (Seymour, Main Arm) of Shuswap Lake would increase its productivity, the lake's physical environment would likely prevent efficient transfer of additional energy to sockeye fry. Further, Shuswap Lake and the surrounding area are heavily used for recreational and residential purposes, and a lake fertilization program would possibly be socially unacceptable. Increasing fry recruitment through increased escapements would be the most effective way of rebuilding Shuswap sockeye stocks (Table 7).

Stuart Lake

Limnological data from Stuart Lake were collected once monthly (May to October) from 1996-1998 and limnetic fish data were collected in spring and fall of the same years. With a surface area of 359 km², Stuart is the largest lake in the Fraser system and the second largest sockeye nursery lake in B.C. (Table 1). Compared to most other large B.C. sockeye lakes, Stuart is relatively shallow, with a mean depth of 20 m and a maximum depth of only 45 m. During our study, frequent winds and considerable fetch in the main basin resulted in an average thermocline depth of 20.3 m (Table 2). Mean epilimnetic temperature was 13.6ºC and during summer, the majority of the lake's volume was within the epilimnion. The lake was organically stained and the euphotic zone depth averaged only 6.6 m (n=3, ±2SE=15%). Spring overturn total phosphorus concentration was 9.8 µg/L (n=3, ±2SE=16%), placing the lake at the top of the oligotrophic range (Table 3). Spring overturn nitrate concentrations averaged 37 µg N/L (n=3, ±2SE=70%), and given appropriate physical conditions (periods with little wind), summer epilimnetic nitrate approached depletion. The seasonal average chlorophyll concentration of 1.92 µg/L (n=3, ±2SE=8%) was similar to that in Shuswap Lake and the PR_{mean} of 138 mg $C \cdot m^{-2} \cdot d^{-1}$ (n=3, ±2SE=9%)was similar to that in Babine Lake (Table 4). PR_{mean} was somewhat lower than would normally be expected from a lake with this nutrient load and was most likely due to the relatively shallow euphotic zone and deep epilimnion (i.e. light limitation). The chemical and biological data indicate Stuart Lake is in the upper range of oligotrophy and is more productive than the majority of B.C. sockeye nursery lakes. With a seasonal average of

1,410 mg dry wt/m^2 (n=3, ±2SE=1%), macrozooplankton biomass was the highest of any Fraser system sockeye lake with the exceptions of Anderson Lake and meso-eutrophic Fraser Lake. *Daphnia* biomass averaged 139 mg dry wt/m^2 (n=3, ±2SE=55%) and biomass of the large copepod *Heterocope septentrionalis* was slightly less (98 mg dry wt/m^2). Zooplankton biomass was composed primarily of the copepods *Leptodiaptomus pribilofensis* (626 mg dry wt/m^2) and *Diacyclops thomasi* (455 mg dry wt/m^2). Sockeye fry diet was primarily of *Daphnia* and *Heterocope*. During our study, Stuart Lake *O. nerka* densities were low (mean=418/ha) and kokanee averaged about 53% of the population (J. Hume unpublished data) (Table 5). After correcting for the kokanee population sockeye, fry fall densities ranged from 130-355/ha. Mean fall *O. nerka* fry ranged from 2.5 to 3.9 g in size, indicating an adequate food supply at the low limnetic fish densities present.

Stuart Lake sockeye comprise about 75% of what is commonly called the Late Stuart run, with the remainder of Late Stuart sockeye rearing in Trembleur Lake. Average escapement to the lake is 279,000, substantially lower than the PR model predicted optimum escapement of 1,659,000 (Table 6). This suggests that increased fry recruitment is needed to increase the abundance of this stock. Stuart Lake sockeye have a long (1,000 km) migration up the Fraser, Nechako, and Stuart rivers to their primary spawning stream. In some years, warm temperatures or high river discharge results in substantial pre-spawning mortality (MacDonald et al. 2000) and these migration problems are likely to be exacerbated by global climate change (Levy 1992). Consequently, stable or increased fry recruitment from adult spawners is unlikely (Table 7). While Stuart Lake has the productive capacity to be one of the largest sockeye producers in B.C., the long and frequently difficult migration means restoration of its sockeye stocks is less probable than restoration of other stocks with shorter migration routes.

Takla Lake

Limnological data from Takla Lake were collected once monthly (May to October) from 1996-1998 and limnetic fish data were collected in spring and fall of the same years. Takla is a large (surface area=246 km^2) lake that is the uppermost of the three large lakes that make up the Stuart system lakes (Table 1). It is a fiord-type lake with a mean depth of 107 m and a mean epilimnetic temperature of 11.6°C (Table 2). Prevailing winds do not blow down the longitudinal axis of the lake, resulting in a stable summer thermocline with an average depth of 13.7 m. At the time of sampling, the lake was organically stained and the euphotic zone depth averaged only 6.9 m. The spring overturn total phosphorus concentrations of 4.7 µg/L were near the mid-range of oligotrophy (Table 3). Nitrogen supply was relatively high, with spring overturn nitrate concentrations of 74 µg N/L (n=3, ±2SE=7%). Epilimnetic nitrate was not depleted in summer (minimum summer nitrate=29 µg N/L). Seasonal average chlorophyll concentration was 1.02 µg/L (n=3, ±2SE=17%)and the PR_{mean} of 55 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$ (n=3, ±2SE=24%) is the lowest yet recorded for a Fraser system sockeye nursery lake (Table 4). These data indicate that the lake was less productive than its phosphorus load would indicate. Reasons for this can be partly attributed to the relatively shallow euphotic zone, but may also be associated with the proportion of the total phosphorus that was biologically available. Average zooplankton biomass was 562 mg dry wt/m^2 (n=3, ±2SE=16%) for macrozooplankton and 91 mg dry wt/m^2 (n=3, ±2SE=43%) for *Daphnia*. The less desirable copepods, *Leptodiaptomus (L. pribilofensis)* and *Diacyclops* (*D. thomasi*), made up 73% of the total macrozooplankton biomass. Sockeye fry diet was composed primarily of their preferred prey, *Daphnia*. During our study, Takla Lake *O. nerka* densities were low (mean=252/ha) and kokanee averaged about 53% of the population (protein electrophoretic separation, J. Hume unpublished data) (Table 5). After correcting for the kokanee population sockeye fry fall densities ranged from 59-137/ha.

Mean fall *O. nerka* fry ranged from 2.5-3.9 g in size, indicating an adequate food supply at the low limnetic fish densities present.

Takla Lake sockeye comprise about 75% of the Early Stuart run, with the remainder of Early Stuart sockeye rearing in Trembleur Lake. The PR model predicts an optimum escapement of 453,000 (Shortreed et al. 1999) and indicates that the lake could support approximately 10 times more sockeye fry than were present during our study (Table 6). Early Stuart sockeye have more severe migration difficulties than Late Stuart sockeye because their earlier run timing often coincides with seasonal maximum Fraser River flows. They also have a longer migration route (1,178 km to the major spawning stream). Increased fry recruitment is needed to restore the abundance of this stock but, like Late Stuart sockeye, the difficult migration makes increasing sockeye production highly uncertain. If fry densities were substantially higher, it is probable that lake fertilization would be of benefit to the growth and survival of Takla Lake sockeye fry (Table 7).

Taseko Lake

We carried out a limnological survey of Taseko Lake on one occasion in early October of 1981. Taseko Lake has a surface area of 31 km² and a mean depth of 43 m (Table 1). At the time of our survey, surface temperature was 8.2°C and the lake was highly turbid from glacial inflows which resulted in a euphotic zone depth of only 1.8 m (Table 2). The chlorophyll concentration of 0.35 µg/L was among the lowest recorded for that time of year for any B.C. sockeye nursery lake (Table 4). Zooplankton biomass was very low (120 mg dry wt/m²) as well. No limnetic fish data are available for Taseko Lake. Estimated sockeye escapements to Taseko Lake are <3,000 spawners in most years but, given the turbidity of the water and the visual enumeration methods used, the estimates are tentative at best (Table 6). Even with the limited available data it is clear that the productivity of Taseko Lake is strongly light-limited so there is little likelihood of increasing lake productivity. The advisability of increasing fry recruitment cannot be determined without improved escapement estimates, and without data on the number and size of limnetic fish (Table 7).

Trembleur Lake

Located between Takla and Stuart lakes, Trembleur Lake is the smallest (surface area=116 km²) of the three Stuart system lakes (Table 1). As with the other two lakes in the system, limnological data and limnetic fish data were collected from 1996-1998. With a mean depth of 40 m, Trembleur Lake is substantially shallower than Takla Lake. At the time of our study, the lake had a mean epilimnetic temperature of 12.2°C and frequent westerly winds resulted in an average thermocline depth of 20.0 m (Table 2). It was organically stained and had an average euphotic zone depth of only 6.0 m (n=3, ±2SE=15%). Its nutrient loading placed it in the upper range of oligotrophy, with spring overturn concentrations of 8.8 µg/L (n=3, ±2SE=26%) for total phosphorus and 57 µg N/L (n=3, ±2SE=23%) for nitrate (Table 3). The PR_{mean} of 84 mg $C \cdot m^{-2} \cdot d^{-1}$ (n=3, ±2SE=29%) was lower than would normally be expected from a lake with this nutrient load. This was most likely due to the shallow euphotic zone and the relatively deep epilimnion (i.e. light limitation) (Table 4). Trembleur Lake has an abundant zooplankton community, and during our study, macrozooplankton biomass averaged 1,134 mg dry wt/m² (n=3, ±2SE=15%) and *Daphnia* biomass averaged 231 mg dry wt/m² (n=3, ±2SE=20%). As in Takla Lake, *Daphnia* comprised the major proportion of the sockeye diet.

As with Stuart and Takla lakes, Trembleur Lake has a substantial kokanee population which averaged 48% of total *O. nerka* numbers in 1996 and 1997. *O. nerka* fall densities averaged 390/ha while sockeye fry ranged from 73-246 /ha during our study (Table 5). Of the three Stuart system lakes, Trembleur had the largest (mean=5.1 g) fall sockeye fry. Of sockeye juveniles which rear in Trembleur Lake, an average of 35% (based on female spawners) are from the Early Stuart run and the remainder are from the Late Stuart run. Trembleur Lake provides an excellent rearing environment for juvenile sockeye and with an optimum escapement of 326,000 predicted by the PR model, the lake could sustain an order of magnitude greater fry numbers than were present during our study (Table 6). Restoration of Trembleur sockeye will require increased fry recruitment, but as with Stuart and Takla Lake sockeye, the difficult migration makes increasing sockeye production highly uncertain (Table 7).

Central Coast

Charlotte Lake

Charlotte Lake is located on the Chilcotin plateau at the relatively high elevation of 1,169 m (Table 1). It drains into the upper portion of the Atnarko River and is not accessible to anadromous fish because of impassible river sections. On one occasion in early September of 1997, we carried out limnological and limnetic fish surveys of the lake. The lake is relatively large (surface area=66 km^2) and has a mean depth of 41 m. At the time of our survey, the lake had a stable, 15.2 m deep epilimnion and clear water (euphotic zone depth=22.1 m) (Table 2). Epilimnetic nitrate concentrations were very low (average=1.7 µg N/L) and, while spring overturn data are not available, hypolimnetic nitrate concentrations averaged only 11 µg N/L (Table 3). Total phosphorus concentration was 3.8 µg/L. Since the euphotic zone was considerably deeper than the thermocline, substantial phytoplankton production occurred within the hypolimnion. This resulted in nitrate depletion well into the hypolimnion, effectively reducing vertical transport of nutrients. Accordingly, epilimnetic chlorophyll was very low (0.47 µg/L) and photosynthetic rate on the day of the survey was only 76 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). The lake's physical environment and low nutrient loading contributed to its oligotrophic status. Despite this, macrozooplankton biomass was quite high (1,459 mg dry wt/m^2) with large *Daphnia* making up 46% of this total. The high plankton biomass can be attributed to a large extent to the lack of limnetic planktivores in the lake, making the zooplankton community an unexploited food resource. The lake could sustain substantial numbers of juvenile sockeye, and since it is not accessible to adult spawners, fry outplants would be the only way to use Charlotte Lake to increase Atnarko sockeye numbers. The PR model predicts that the lake could sustain a spring recruitment of 22 million fry (optimum escapement=169,000) (Table 6). However, the lake's low productivity suggests that its plankton community would be unable to sustain substantial grazing pressure. Therefore, we suggest fry additions should not exceed 50% of the PR model prediction (Table 7).

Elbow Lake

We carried out a limnological survey of Elbow Lake on one occasion in early September of 1999. The lake is on the Atnarko River and is the furthest upstream of Atnarko sockeye nursery lakes. Sockeye escapement to the Atnarko system lakes (Elbow, Lonesome, and Rainbow) average 33,000 (range: 15,000-55,000) but it is not known what proportion of their progeny, if any, rear in Elbow Lake. The lake has a surface area of only 1.5 km^2 and a mean depth of 14 m (Table 1). At the time of our survey, surface temperature was 13.5°C, thermocline depth was 13.0 m, and euphotic zone depth was 7.9 m (Table 2). Assuming that hypolimnetic total phosphorus concentration at the time of our survey was similar to spring overturn total phosphorus, the value of 4.6 µg/L places the lake in the middle range of oligotrophy (Table 3). Hypolimnetic nitrate was relatively high (54 µg N/L). Chlorophyll concentration was low (0.75 µg/L), as was the daily photosynthetic rate of 54 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). Macrozooplankton biomass was 1,089 mg dry wt/m², which was only 55% of the macrozooplankton biomass found in nearby Lonesome Lake. *Daphnia* biomass was 5.7 times lower than what occurred in Lonesome Lake, and made up only 25% of Elbow Lake macrozooplankton biomass. Based on the single sampling date, Elbow Lake appears to have a favorable physical environment for juvenile sockeye. The low macrozooplankton biomass in Elbow Lake relative to nearby Lonesome Lake, the much lower *Daphnia* biomass, and the higher relative abundance of predation-resistant copepods, suggests that Elbow Lake currently has higher planktivore numbers than does Lonesome Lake. The PR model predicts (assuming the single September data point is similar to the seasonal average) that 2,000 spawners would be the optimum escapement to Elbow Lake (Table 6). Increased fry recruitment (e.g. outplants) may be needed for restoration of Elbow Lake sockeye, but more data on the lake's current productive capacity, on spawning ground capacity, on current escapements, and on its limnetic fish community are needed before this can be confirmed (Table 7).

Lonesome Lake

We carried out a limnological survey of Lonesome Lake on one occasion in early September of 1999. The Lake is part of the Atnarko system and is located downstream of Elbow and Rainbow lakes. These three lakes are the only potential sockeye nursery lakes in the Atnarko system accessible to anadromous fish and Lonesome Lake is the largest of these with a surface area of 4.1 km² and a mean depth of 14 m (Table 1). During our survey, surface temperature was 14.8°C and a well-developed thermocline was present at a depth of 14.0 m (Table 2). The lake was relatively clear, with a euphotic zone depth of 11.7 m. Assuming hypolimnetic total phosphorus concentration at the time of our survey was similar to spring overturn total phosphorus, the value of 6.1 µg/L places the lake in the middle to upper range of oligotrophy (Table 3). Epilimnetic nitrate concentration was low (2.1 µg N/L) and hypolimnetic nitrate was substantially higher (31 µg N/L). Epilimnetic chlorophyll concentration was low (0.60 µg/L), as was the daily photosynthetic rate of 78 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). The macrozooplankton biomass of 1,982 mg dry wt/m² was among the highest recorded for a B.C. sockeye nursery lake and probably accounted for the low phytoplankton biomass (i.e. high grazing pressure on the phytoplankton community). *Daphnia* biomass (1,572 mg dry wt/m²) was also unusually high. The PR model predicts an optimum escapement to Lonesome Lake of 11,000 (Table 6). In recent years, sockeye escapements to Atnarko system lakes (Elbow, Lonesome, and Rainbow) exceed this optimum (average 33,000; range 15,000-55,000), but it is not known what proportion of their progeny rear in Lonesome Lake. Our data indicate that Lonesome Lake has a favorable physical environment and, at the time of our survey, had an under-exploited population of large *Daphnia*. Data further suggest that at current productivity levels the lake could sustain substantially larger numbers of sockeye than it currently does. Therefore, increased fry recruitment is likely needed for restoration/enhancement of this stock, but further data and a better understanding of the lake's current productive capacity, spawning ground capacity, escapements, and limnetic fish community are needed before it can be determined how this would be best accomplished (Table 7).

Long Lake

Long Lake is located on B.C.'s central coast and drains into Smith Inlet via the Docee River and Wyclees Lagoon. Until recently, the lake had one of the largest sockeye stocks on B.C.'s central coast, with average escapements of 117,000 since the early 1970's (Rutherford and Wood 2000a) (Table 6). However, in the late 1990's stock size declined precipitously, with the 1999 escapement at a historic low of 5,900. The lake was fertilized for most of the past 25 yr (1977-1979, 1982-1985 and 1987-1997). Limnological sampling was carried out twice monthly from April to November in 1977 and monthly (April to November) from 1978 to 1983 (Shortreed and Stockner 1981; Costella et al. 1982; Stockner and Hyatt 1984). Unfertilized data reported here are from 1980 and 1981. Annual acoustic and trawl surveys have been carried out at the lake since 1977 (Hyatt et al. 2000). As with most lakes located near the B.C. coast, Long Lake is warm monomictic, with high annual precipitation and a rapid flushing rate (water residence time=1.1 yr) (Table 1). Frequent high rainfall in the fall and winter causes sudden freshets in streams entering the lake. As a result, spawning grounds can be unstable and egg-to-fry survival may be low relative to streams with more stable flows (Thorne and Ames 1987).

Long Lake is organically stained and had average euphotic zone depth of 7.3 m. It had a stable seasonal thermocline (mean depth=10.0 m) and a cool epilimnion (seasonal average=13.5°C) (Table 2). As with many coastal lakes, Long Lake was slightly acidic (mean pH=6.40) and was poorly buffered with a total alkalinity of only 3.1 mg $CaCO_3$/L. The lake was oligotrophic, with spring overturn nitrate concentrations of 62 µg N/L and total phosphorus concentrations of 3.4 µg/L (Table 3). Seasonal average chlorophyll concentrations were relatively high (2.24 µg/L) despite a PR_{mean} of only 70 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). Average zooplankton biomass was 180 mg dry wt/m^2, considerably lower than that found in many interior lakes but similar to that found in a number of coastal lakes. During fertilized years, PR_{mean} averaged 297 mg $C \cdot m^{-2} \cdot d^{-1}$, 4.2 times higher than during unfertilized years. Average chlorophyll concentration increased to 2.48 µg/L during fertilized years and zooplankton biomass more than doubled to 420 mg dry wt/m^2. During two years with similar limnetic fish densities (ca. 3,000/ha), smolts averaged 3.0 g (unfertilized) and 4.9 g (fertilized) (Hyatt and Stockner 1985). The PR model predicts that optimum escapement to Long Lake is 49,000 under natural conditions and >209,000 when the lake is fertilized (Table 6). However, given low average egg-to-fry survivals in Long and other coastal lakes, PR model predictions of optimum escapement may underestimate the actual optimum. Further, in some years Long Lake has had a substantial stickleback population, reducing its rearing capacity for juvenile sockeye.

Long Lake has not been fertilized since 1997 because of the extremely low recent escapements. At these low escapements, freshwater survival of sockeye fry appears to be substantially higher (Hyatt et al. 2000) and fertilization may not be warranted. Whether fertilization is resumed should be dependent on further analysis of the effects of the previous years of fertilization on sockeye production and on escapement numbers (Table 7).

Nimpkish Lake

Nimpkish Lake is located on northern Vancouver Island and drains via the Nimpkish River into the northern end of Johnston Strait. The Nimpkish River system contains a number of lakes, with Nimpkish Lake being the largest (surface area=37 km^2) by a substantial margin. Escapement estimates to the Nimpkish system are relatively uncertain, but available data indicate that from 1987-1997 they ranged from 20,000-237,000 (mean=81,000) (Table 6). In recent years escapements have declined rapidly to only a few thousand spawners (P. Rankin, Fisheries and Oceans Canada, personal communication). The proportion of the progeny from sockeye spawners which respectively rear in the four Nimpkish system sockeye nursery lakes (Nimpkish, Woss, Vernon, Schoen) is not known, but it is believed the majority rear in Nimpkish and Woss lakes. The major river spawning in the system occurs in the Woss River between Woss and Nimpkish lakes, but substantial beach spawning has been observed in several of the lakes (Simpson et al. 1981). Nimpkish Lake was fertilized from 1982-1987 and in 1989. Limnological sampling was carried out at the lake monthly in 1978, 1979, and from 1982-1986. Annual acoustic and trawl surveys were carried out for a number of years between the late 1970's and the 1990's (K. Hyatt, Fisheries and Oceans Canada, personal communication).

As with most lakes located near the B.C. coast, Nimpkish Lake is warm monomictic. The lake has a large (1,648 km²) drainage basin which receives high annual precipitation, resulting in a water residence time of only 1.4 yr (Table 1). Nimpkish Lake has a mean depth of 162 m. The average thermocline depth of 27.4 m was substantially deeper than that found in most coastal lakes and the average epilimnetic temperature was a relatively cool 13.2°C (Table 2). The average euphotic zone depth was 11.7 m. The lake is highly oligotrophic, with spring overturn nitrate concentrations of 48 µg N/L and spring overturn total phosphorus concentrations of <2.0 µg/L (Table 3). Epilimnetic nitrate was not depleted during the growing season and seasonal minima were 28 µg N/L. Plankton biomass was very low even for an oligotrophic coastal lakes, with mean epilimnetic chlorophyll concentrations of 0.80 µg/L, a PR_{mean} of 80 mg $C \cdot m^{-2} \cdot d^{-1}$, and an average zooplankton biomass of only 73 mg dry wt/m² (Table 4). Size of Nimpkish sockeye smolts averaged 2.6 g (Hyatt and Stockner 1985) in two unfertilized years (1980 and 1981) when reported brood year escapements to the entire Nimpkish system were low (20,000-24,000).

The lake's plankton communities responded substantially to fertilizer additions, with a 2.2-fold increase in average chlorophyll concentration and a 3.5-fold increase in zooplankton biomass (Table 4). Given the lake's strong P-limitation and highly oligotrophic status, it is probable that fertilizer additions would also result in increased growth and/or survival of juvenile sockeye. Size of smolts resulting from the current very low escapements would help determine whether fertilization would be of benefit at present. Improved information is needed on the number of sockeye stocks and their lake of origin throughout the Nimpkish system. If spawner numbers increase, available data indicate that Nimpkish Lake is a highly favorable candidate for fertilization. Increasing recruitment through fry outplants would help accelerate restoration of this stock (Table 7).

Owikeno Lake

Owikeno is a large (91 km²), fiord-type lake (mean depth=172 m) which drains into Rivers Inlet on the central coast (Table 1). The lake consists of three small upper basins and a fourth, much larger lower basin. Monthly limnological surveys were carried out from April to November of 1978 (Stockner and Shortreed 1979) and a single survey was done in June of 1996 (E. MacIsaac, Fisheries and Oceans Canada, personal communication). Limnetic fish surveys have been carried out on a number of occasions by several different investigators from the 1960's to the present. Owikeno Lake's drainage basin is large (approximately 3,621 km²) and precipitation is high, with the result that the lake's water residence time is only two years. Frequent, strong outflow winds occur and several of the lake's major tributaries are cold and glacially turbid. These influences resulted in a cool epilimnion (main basin surface temperatures did not exceed 15°C) and a deep (31 m), weak thermocline during the 1978 study (Table 2). The glacially turbid inflows also contributed to an average euphotic zone depth of only 5.3 m. The lake had an abundant nitrogen supply, with spring overturn nitrate concentrations of

100 µg N/L (Table 3). After spring overturn in 1978, epilimnetic nitrate declined rapidly to summer minima of approximately 20 µg N/L in the main basin and <5 µg N/L in the upper basins. Spring overturn total phosphorus data are not available, but in June 1996 hypolimnetic total phosphorus concentration (corrected for turbidity) was 6.9 µg/L. Nutrient data places the lake in the middle to upper range of oligotrophy, but average chlorophyll (mean=0.94 µg/L) and PR_{mean} (78 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$) indicate a more oligotrophic status, most likely as a result of the rapid light attenuation (Table 4). Zooplankton biomass averaged only 155 mg dry wt/m² in 1978 and was dominated by diaptomid and cyclopid copepods (Rankin and Ashton 1980). Until recently, the lake had the largest sockeye stock on B.C.'s central coast, with an average escapements of 214,711 over the past 10 yr (Rutherford and Wood 2000a). This approached the predicted optimum escapement of 239,000 (Table 6). However, in the late 1990's stock size declined precipitously, with the 1999 escapement at a historic low of 3,600. Historically, Owikeno Lake has produced very small sockeye smolts (mean=0.7 g) (Table 5) but at the recent very low escapements, fry size is substantially larger, but still <3 g (Rutherford and Wood 2000b). Lake fertilization would most likely increase phytoplankton productivity within Owikeno Lake, but given the relatively turbid water and the deep thermocline, the response to a particular fertilizer loading rate would be less than in a lake with clearer water and more stable thermal stratification. To ensure zooplankton productivity was effectively increased, the fertilizer loading rate would have to be higher than is the normal practice. If Owikeno sockeye stocks rebuild, lake fertilization would likely be of substantial benefit. However, since very low spawner densities produce larger smolts, benefits from fertilizer applications prior to some stock rebuilding would be less (Table 7).

Rainbow Lake

We carried out a limnological survey of Rainbow Lake on one occasion in early September of 1999. Rainbow Lake is located on the Atnarko River about 8 km upstream of Lonesome Lake. It is small (surface area=1.7 km²) and has a mean depth of only 3.8 m (Table 1). At the time of our survey, surface temperature was 14.6°C and the lake was isothermal (total depth at the sampling location was only 8 m) (Table 2). The water was clear (the euphotic zone of 9.6 m was greater than the lake's maximum depth) and the entire lake was within the littoral zone. The total phosphorus concentration of 4.4 µg/L places the lake in the lower to middle range of oligotrophy (Table 3). Nitrate concentrations were low throughout the water column and averaged only 2.4 µg N/L. Chlorophyll concentration was low (0.63 µg/L), as was the daily photosynthetic rate of 55 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$ (Table 4). Macrozooplankton biomass was high (674 mg dry wt/m² in only an 8 m water column) and *Daphnia* made up 96% of the total. The PR model predicts (assuming the single September data point is similar to the seasonal average) an optimum escapement to Rainbow Lake of 3,000. This is much lower than the average sockeye escapement of 33,000 (range: 15,000-55,000) to the Atnarko system lakes (Elbow, Lonesome, and Rainbow), but it is not known what proportion, if any, of their progeny rear in Rainbow Lake (Table 6). However, the high *Daphnia* biomass suggests that planktivorous fish density in the lake was low and that this prime food resource was under-exploited. Despite an ample food supply, the lake is shallow and may not provide juvenile sockeye with a suitable physical environment for a portion of the growing season. We recommend that additional data on spawning ground capacity, current escapements, limnetic fish community, and lake physical environment are needed before the potential to produce additional Rainbow Lake sockeye can be determined (Table 7).

Woss Lake

Woss Lake is the second largest lake (surface area=13 km²) in the Nimpkish River system on northern Vancouver Island. It drains via the Nimpkish River into Nimpkish Lake. Escapements to Woss Lake are not available, but available data indicate that from 1987-1997 they ranged from 20,000 to 237,000 (mean=81,000) to the entire Nimpkish River system. More recently, escapements have declined rapidly to only a few thousand spawners (P. Rankin, Fisheries and Oceans Canada, personal communication). The proportion of the progeny from sockeye spawners which rear in each of the four Nimpkish system sockeye nursery lakes (Nimpkish, Woss, Vernon, Schoen) is not known, but it is believed the majority rear in Woss and Nimpkish lakes. The major river spawning in the system occurs in the Nimpkish River between Woss and Nimpkish lakes, but substantial beach spawning has been observed in several of the lakes (Simpson et al. 1981). Monthly limnological sampling was carried out at the lake in 1978, 1979, and 1982. Annual acoustic and trawl surveys were carried out for a number of years between the late 1970's and the 1990's (K. Hyatt, Fisheries and Oceans Canada, personal communication). Woss Lake was fertilized in 1988 and 1989 but no limnological sampling was carried out at that time. Fertilization and sampling of Woss Lake was resumed in 2000 (D. Mackinlay, Fisheries and Oceans Canada, personal communication).

As with most lakes located near the B.C. coast, Woss Lake is warm monomictic. It has a mean depth of 81 m and an average thermocline depth of 18.3 m (Table 2). With an average euphotic zone depth of 13.7 m, water clarity was greater than for most coastal B.C. lakes. The lake was highly oligotrophic, with spring overturn total phosphorus concentrations of only 1.2 µg/L and spring overturn nitrate concentrations of 38 µg N/L. (Table 3). Plankton biomass was low (although higher than in nearby Nimpkish Lake), with mean epilimnetic chlorophyll concentrations of 0.96 µg/L, a PR_{mean} of 122 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$, and an average zooplankton biomass of 191 mg dry wt/m² (Table 4). Zooplankton community structure was also indicative of a highly oligotrophic lake, with dominant species being the copepod *Cyclops bicuspidatus* and the small cladoceran *Bosmina longispina* (Rankin and Ashton 1980). In the late fall of 1978, Woss Lake fall fry averaged only 1.5 g despite low (537/ha) densities (Simpson et al. 1981), further confirming the lake's highly oligotrophic status.

With its favorable physical environment, strong P-limitation, and depauperate plankton community, Woss Lake is a highly favorable candidate for fertilizer additions, with a high probability that they would result in increased growth and/or survival of juvenile sockeye. Improved information is needed on the number of sockeye stocks and their lake of origin throughout the Nimpkish system. Increasing recruitment through fry outplants would help accelerate restoration of this stock (Table 7).

Lower Fraser

Chilliwack Lake

We carried out limnological surveys of Chilliwack Lake on four occasions in the spring and summer of 1997 and 1998. Limnetic fish surveys were done in the summer and fall of 1997. The lake has a surface area of 12 km², a mean depth of 67 m, and a water residence time of only 1.3 yr (Table 1). On the only sampling date (July 17, 1997) when the lake was stratified, surface temperatures were cool (12.7°C), but this may have been anomalously low because of cool spring weather in that year. In contrast, surface temperatures were already 9.5°C by late April 1998. Thermocline depth on the July 1997 sampling date was shallow (5 m). Chilliwack Lake had clear water, with average euphotic zone depths of 13.5 m (Table 2). Spring overturn total phosphorus concentration was low (2.1 µg/L) and there was a relatively abundant nitrogen supply (spring overturn nitrate concentrations averaged 83 µg N/L) (Table 3). Chlorophyll averaged only 0.60 µg/L and photosynthetic rates were also low (88 mg $C \cdot m^{-2} \cdot d^{-1}$) (Table 4). Available data indicate the lake was highly oligotrophic and strongly P-limited. Average macrozooplankton biomass was 219 mg dry wt/m² and *Daphnia* biomass averaged 24 mg dry wt/m². Since these data were collected in spring and early summer, seasonal averages would be higher. The dominant genus in Chilliwack Lake was the copepod *Leptodiaptomus* (primarily *L. ashlandi)*, which had an average biomass of 150 mg dry wt/m².

In the fall of 1998, average size of age-0 *O. nerka* was 4.0 g and their density was 765/ha (Table 5). An unknown proportion of these fish were kokanee, so it is likely that average sockeye size was larger. These data indicate although the lake is oligotrophic, its productive capacity is sufficient for adequate growth of the numbers of planktivorous fish currently present in the lake. Recorded escapements to Chilliwack Lake have never exceeded 8,100 spawners, which is well below the tentative predicted optimum escapement of 36,000 (Table 6). However, since escapement estimates have been derived from infrequent visual surveys (Schubert 1998), actual spawner numbers are no doubt higher. Although small, Chilliwack Lake appears to be an effective rearing area for juvenile sockeye. Increased fry recruitment (higher escapements or outplants) are needed for restoration of this stock. At higher fry densities, the lake and its fish stocks would likely respond positively to fertilizer additions. Additional data are needed to confirm these tentative conclusions (Table 7).

Harrison Lake

We began a three year limnological and limnetic fish study of Harrison Lake in 1999. Data presented here are taken from 1999 and 2000. Harrison is a large (surface area=220 km²), deep (mean depth=151 m) lake located in the lower portion of the Fraser River system (Table 1). During the sampling period, thermal stratification was relatively weak and average thermocline depth was 21.4 m (Table 2). Mean epilimnetic temperature was 12.6ºC. Glacially turbid water entered the upper end of the lake via the Lillooet River and euphotic zone depths averaged 11.2 m. Spring overturn total phosphorus concentrations were 4.0 µg/L and spring overturn nitrate concentrations were 59 µg N/L (Table 3). Summer nitrate concentrations did not fall below 26 µg N/L. Seasonal average chlorophyll concentrations were 0.75 µg/L and PR_{mean} was 107 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). The average macrozooplankton biomass of 572 mg dry wt/m² was low relative to more productive nursery lakes in the B.C. interior, but higher than those observed on many coastal B.C. nursery lakes. *Daphnia* were present in very low numbers (average biomass was <1 mg dry wt/m²).

Sockeye diet in Harrison Lake was diverse, with major components being copepods (*Diacyclops, Epischura*, and *Leptodiaptomus*) and insect larvae. Harrison Lake had a complex limnetic community, which in addition to juvenile sockeye included substantial numbers of planktivorous pygmy longfin smelt (*Spirinchus thaleichthys*), smaller numbers of stickleback (*Gasterosteus aculeatus*), and some mysids (*Neomysis relicta*). Competition among these species would have a substantial effect on the lake's productive capacity for sockeye. Preliminary analyses indicate that smelt and sockeye target similar prey items. Consequently, smelt biomass must be taken into account before the lake's productive capacity for sockeye can be estimated. Sockeye stomachs collected in 1999 were <50% full. Despite this, fall sockeye fry averaged 5.6 g, substantially larger than those found in most coastal lakes or even in many interior nursery lakes (Table 5). Numbers of sockeye in the lake were in the range expected from the estimated numbers of spawners in the previous year. Thus, it appears that survival of

Harrison sockeye is well within the range normally observed for sockeye nursery lakes, and that growth rates are higher than normally observed.

The combined escapements to Harrison Lake and the much smaller (35 km²) Lillooet Lake average 189,000 spawners, substantially less than the predicted optimum for Harrison Lake of 796,000 (Table 6). Returning Harrison-Lillooet sockeye have a relatively short (range: 117-270 km) upstream migration with a minimal elevation gain. Consequently, their migration is energetically far less demanding than that of most Fraser sockeye stocks. Furthermore, the large glacial inflows to Lillooet Lake ensure that excessively warm temperatures do not occur in either lake at any time. These two factors suggest that the Harrison-Lillooet sockeye are less susceptible to global climate change than upper Fraser stocks. Major spawning areas are the Birkenhead River at the head of Lillooet Lake and Weaver Creek spawning channel downstream of Harrison Lake. Most Weaver sockeye fry rear in Harrison Lake. Some Birkenhead fry rear in Lillooet Lake and a substantial but variable proportion migrate downstream and rear in Harrison Lake (Cave 1988).

Currently available data suggest that Harrison Lake could support substantially higher numbers of sockeye than were present in the lake in 1999. Predicted optimum escapements from the PR model (Harrison and Lillooet combined) are 0.96 million, substantially higher than any escapement recorded to date, but competition with other planktivores may reduce this estimate (Table 6). Increased fry recruitment is needed and when higher fry numbers are present, fertilization would possibly be of substantial benefit (Table 7). Construction of a spawning channel on the Birkenhead River and expansion of the Weaver Creek spawning channel could be considered.

Lillooet Lake

Limnological data from Lillooet Lake were collected once monthly from May to October of 2000 and an acoustic survey was carried out in September of 1999. Trawl surveys have been carried out on three occasions from the 1970's to 1999. Lillooet has a surface area of 35 km² and a mean depth of 62 m (Table 1). Two major tributaries enter the upper end of the lake. The Birkenhead River provides the majority of the sockeye spawning ground capacity and the glacially turbid Lillooet River provides the majority of the inflow (its average annual discharge is approximately 5-fold greater than that of the Birkenhead River). The lake has a short (0.5 yr) water residence time and the glacially turbid inflows from the Lillooet River resulted in a cool epilimnion (mean temp=11.9ºC), a relatively weak thermocline averaging 39.3 m in depth, and an average euphotic zone depth of only 4.5 m (Table 2). Euphotic zone depth was highest (7.8 m) in May and declined rapidly to the seasonal minimum of 1.7 m in August. In general, the lake provided a good physical habitat for sockeye fry. Nutrient loading was relatively high, with spring overturn nitrate concentrations of 63 µg N/L and a spring overturn total phosphorus concentration (9.6 µg/L) that put the lake very close to mesotrophic status (Table 3). Given the high nutrient loading, the shallow euphotic zone was the major factor limiting the lake's productivity. Despite the turbid water and deep epilimnion, productivity was sufficient to reduce summer nitrate concentrations to very low (1.2 µg N/L) levels. With a seasonal average photosynthetic rate of 144 mg $C \cdot m^{-2} \cdot d^{-1}$ and chlorophyll concentration of 1.63 µg Chl/L, phytoplankton productivity and biomass were higher than in many other Fraser system lakes and substantially higher than expected given the turbid water (Table 4). Zooplankton biomass was highest in May and had a relatively low seasonal average of 139 mg dry wt/m². The zooplankton community was simple, with the diaptomid copepod *Leptodiaptomous* making up 91% of the seasonal average biomass and the calanoid copepod

Epischura sp. making up a further 7% of the total biomass. Size of age-0 sockeye fall fry averaged 3.6 g (range: 1.7-5.1 g; n=3) (Table 5). With somewhat higher fry densities of 660/ha in 1999, fall fry were substantially smaller, averaging only 1.7 g. At very low fry densities, size increased substantially, indicating density dependent growth (J. Hume, unpublished data). Spawning escapements to the Birkenhead River have averaged 126,128 since the mid-1970's (maximum escapement was 348,294). A variable but sometimes substantial proportion of these fry migrate downstream to rear in Harrison Lake (Cave 1988). With a predicted optimum escapement of 170,000, the productive capacity of Lillooet Lake may be fully utilized in some years, depending on the proportion of fry which rear in Harrison Lake. A greater understanding of the timing and magnitude of early fry emigration to Harrison Lake would be beneficial in refining the Birkenhead optimum escapement estimates. Given the turbidity and the currently high nutrient loading, fertilization of Lillooet Lake would be of little benefit (Table 7).

Pitt Lake

Limnological data from Pitt Lake were collected in July and October of 1989 and March of 1990 (Henderson et al. 1991). Additional zooplankton data were collected in 1978 and 1980. Limnetic fish data were collected between 1977 and 1982 and in the summer and fall of 1989 (Henderson et al. 1991). Pitt Lake has a surface area of 53 km² and a mean depth of 46 m (Table 1). During the sampling period, the lake provided a good physical habitat for sockeye fry, with a cool (mean=12.3°C), deep (mean=14.9 m) epilimnion and an extensive hypolimnion (Table 2). The glacial origin of some lake tributaries produced an average euphotic zone depth (9.3 m) that was only 62% of the average thermocline depth. The lake was oligotrophic and clearly P-limited, with low spring overturn concentrations of total phosphorus (3.3 µg/L) and relatively high spring overturn concentrations of nitrate (117 µg N/L) (Table 3). Chlorophyll concentration averaged 1.2 µg/L and the PR_{mean} of 72 mg $C \cdot m^{-2} \cdot d^{-1}$ is consistent with other unfertilized coastal lakes (Table 4). The lake had relatively low total zooplankton biomass (244 mg dry wt/m²) and *Daphnia* were rare. In the absence of *Daphnia*, large species including the cladoceran *Leptodora kindtii* and the copepod *Epischura*, both desirable prey items, were substantial components of sockeye diet. The small cladoceran *Bosmina* was also heavily grazed by Pitt Lake sockeye fry, even though it is a relatively poor prey item. The availability of larger prey may be responsible for the exceptionally large size (mean=6.5 g) of fall sockeye fry in Pitt Lake (Table 5). In addition to sockeye, the limnetic species longfin smelt (*Spirinchus thaleichthys*) and threespine stickleback (*Gasterosteus aculeatus*) are abundant in Pitt Lake. Both species are potential competitors of juvenile sockeye, but available data for Pitt Lake suggest there is in fact little competition between these species (Henderson et al. 1991; Diewert and Henderson 1992). While Pitt Lake fall fry are among the largest in the Fraser system, freshwater survival rates (potential egg to fall fry) are among the lowest. Available data suggest that most mortality occurs early in lake residence, but reasons for this are not known. Although factors limiting Pitt Lake sockeye stock size are not well understood, we suggest that enhancement/restoration strategies designed to increase fry survival during early lake residence would be most appropriate for Pitt Lake. Fertilizer applications would increase lake productivity, but given the already large size of Pitt sockeye fry, most fertilization benefits would have to come from increased freshwater survival (Table 7). The proportion of the fertilization benefits which would accrue to smelt and stickleback rather than sockeye are not known.

North Coast

Alastair Lake

Alastair Lake is located approximately 60 km southwest of Terrace and drains via the Gitnadoix River, which enters the Skeena River about 20 km north of the lake. The lake and river are both within the Gitnadoix River Recreation Area. Limnological data from Alastair Lake were collected once monthly from May to October (n=6) of 1978 (Stockner and Shortreed 1979; Shortreed et al. 1998). Limnetic fish data were collected once in the fall of 1995 (Shortreed et al. 1998). In 1978, the lake had a suitable physical environment for juvenile sockeye, with a mean depth of 31 m and deep water (>50 m) in the southern end (Table 1). With a mean surface temperature of 14°C, a 10.2 m deep thermocline, and a cool hypolimnion, Alastair Lake's thermal regime was favorable for sockeye (Table 2). Alastair Lake was relatively clear, with an average euphotic zone depth (13.5 m) slightly greater than the thermocline. The lake was very productive, with a PR_{mean} of 209 mg $C \cdot m^{-2} \cdot d^{-1}$, one of the highest photosynthetic rates ever recorded for B.C. sockeye lakes (Table 4). In 1995, Alastair Lake had high densities (>6,200/ha) of limnetic fish (this is an underestimate because of limitations of echo counting at these high densities), of which two-thirds were stickleback and the remainder (1,994/ha) were sockeye (Table 5). Sockeye stomachs were only 20% full and contained nearly 100% *Bosmina*, a low-quality food item. Sockeye fry averaged only 1.7 g in October, most likely because of competition with the large numbers of stickleback. The average escapement of 8,300 is only 17% of the optimum escapement predicted by the PR model (Table 6). However, the lake's rearing capacity is fully utilized or exceeded by the high stickleback numbers. Increasing Alastair Lake sockeye numbers will require a reduction in the lake's stickleback numbers (Table 7).

Awun Lake

Awun Lake is located on Graham Island of the Queen Charlotte Islands. It drains into Masset Inlet via the short (<2 km) Awun River. Monthly limnological sampling was carried out in 1982 and 1983 and the lake was fertilized from 1979-1985 (Stockner and Shortreed 1985). No comparable data for unfertilized years are available, and data presented here are from fertilized years. The lake has a surface area of 4.9 km² and a mean depth of 47 m (Table 1). The area receives high annual precipitation, resulting in an estimated water residence time of only 0.9 yr. Awun Lake stratified strongly during the years it was sampled, with an average epilimnetic temperature of 13.9°C and an average thermocline depth of 10.1 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 5.2 m (Table 2). The lake was slightly acidic and had an average pH of 6.30. It was strongly oligotrophic, with low spring overturn concentrations of both total phosphorus (2.3 µg/L) and nitrate (34 µg N/L) (Table 3). Seasonal average chlorophyll concentration was 1.56 µg/L and average zooplankton biomass was high relative to most other coastal lakes (956 mg dry wt/m²) (Table 4). Smolts were also relatively large, with an average weight of 4.6 g (Hyatt and Stockner 1985). Available sockeye escapement data to Awun Lake indicates that spawner numbers have averaged 2,200 over the past 10 yr. However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The lack of unfertilized data makes it impossible to assess benefits of the previous fertilization. Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on obtaining better and more current data on escapements, on growth and survival of juvenile sockeye, and on the plankton community, and on trophic status (Table 7).

Babine Lake

Babine Lake is the largest sockeye nursery lake in B.C and currently produces 90% of sockeye returns to the Skeena River. In the late 1960's, three spawning channels were constructed on tributaries entering the main basin of the lake. Before this development, adult sockeye returns to Babine Lake averaged 0.5 million; Since, they have averaged 1.4 million (Wood et al. 1998). Limnological data from Babine Lake were collected in 1994 (n=6) and in 1995 (n=9) (Shortreed and Morton 2000) and limnetic fish data were collected from 1993-1995 (Hume and MacLellan 2000). At the time of sampling, this large lake had a relatively cool epilimnion (seasonal average=13.4 °C) and a well developed seasonal thermocline (depth=11.3 m) (Table 2). Babine Lake was organically stained and had an average euphotic zone depth (6.9 m) that was about 60% of its average thermocline depth (Table 2). A seasonal epilimnetic total phosphorus concentration of 5.5 µg/L and a seasonal average chlorophyll concentration of 2.20 µg/L put Babine Lake in the middle to upper range of oligotrophy, as did its PR_{mean} of 140 mg $C \cdot m^{-2} \cdot d^{-1}$ (Tables 3 and 4). Fall fry in Babine Lake were relatively large (3.6 g) during our study (Table 5) and *Daphnia* comprised a major portion of their diet, indicating a good rearing environment. However, *Daphnia* biomass (28 mg dry wt/m^2) in Babine Lake was low relative to other interior nursery lakes having similar sockeye fry densities. In most years sockeye fry densities are higher than during our study and in these years *Daphnia* comprise a much smaller proportion of sockeye diet (Shortreed and Morton 2000). These data and escapements approaching the PR model optimum escapement suggest that fry production from natural spawning areas and from the three spawning channels can fully utilize the lake's rearing capacity (Table 6). If fry recruitment to Babine Lake was further increased, lake fertilization would be required to maintain current fry growth and survival rates (Table 7).

Bear Lake

Located approximately 150 km north of Smithers, Bear Lake drains via the short (10 km) Bear River into the Sustut River, which then discharges into the Skeena River. Limnological data from Bear Lake were collected once monthly in 1978 from June to September (n=4) and limnetic fish data were collected in the fall of 1995 (Stockner and Shortreed 1979; Shortreed et al. 1998). During the survey, Bear Lake had a mean depth of 14 m, an average thermocline depth of 7.5 m, a mean surface temperature of 14.6°C, and a 8.8 m euphotic zone depth (Tables 1 and 2). It had a substantial, cool, hypolimnion which provided a suitable physical environment for juvenile sockeye. Both average photosynthetic rates and average macrozooplankton biomass were among the highest in the Skeena system (Table 4). In 1995, limnetic fish densities were low and were made up of about equal densities of sockeye and whitefish. Sockeye stomachs were 60% full and contained mostly *Daphnia* and *Heterocope*, which are both large and desirable food items. As a result, fall sockeye fry averaged 3.9 g (Table 5). Sockeye escapements averaging 2,600 are <5% of the optimum escapement of 91,000 predicted by the PR model (Table 6). Therefore, increased fry recruitment is the primary element needed for enhancement/restoration of this stock (Table 7).

Bonilla Lake

Bonilla Lake is located near the northern end of Banks Island, approximately 100 km south of Prince Rupert. It drains via a short (<1 km) stream into the head of Kingkown Inlet. Monthly limnological sampling was carried out from 1979-1983 and the lake was fertilized from 1980-1985 (Stockner and Shortreed 1985). It has a surface area of 2.3 km² and a mean depth of 34 m (Table 1). The area receives high annual precipitation, resulting in an estimated water residence time of only one year. Bonilla Lake stratified strongly during the years it was sampled, with an average epilimnetic temperature of 13.6°C and an average thermocline depth of 10.5 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 4.2 m (Table 2). The lake was very poorly buffered (average total alkalinity was 0.8 mg $CaCO_3$/L) and quite acidic, with an average pH of 5.70. The lake was highly oligotrophic and had very low spring overturn concentrations of both total phosphorus (2.1 µg/L) and nitrate (8.0 µg N/L) (Table 3). Under unfertilized conditions, seasonal average chlorophyll concentration was 1.04 µg/L and the PR_{mean} was 122 mg $C \cdot m^{-2} \cdot d^{-1}$ (Shortreed and Stockner 1981). Zooplankton biomass averaged only 281 mg dry wt/m² (Rankin and Radziul 1986; Table 4). Fertilization increased phytoplankton biomass and production in Bonilla Lake substantially, with seasonal average chlorophyll of 4.70 µg/L, a PR_{mean} of 291 mg $C \cdot m^{-2} \cdot d^{-1}$, and average zooplankton biomass of 782 mg dry wt/m² (Table 4). This large response was at least partially due to higher (by 1.5-5 times) fertilizer application rates than those normally used in B.C. sockeye lakes.

Average smolt weight from Bonilla Lake was 1.6 g in 1979, an unfertilized year, and increased 38% to an average of 2.2 g in the following two fertilized years (Hyatt and Stockner 1985; Table 5). Available sockeye escapement data to Bonilla Lake indicates that spawner numbers have averaged 1,300 over the past 10 yr, although several years of higher (>4,000) escapements were recorded in the 1970's (Table 6). However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The PR model prediction for optimum escapement to unfertilized Bonilla Lake is 9,000, suggesting that it currently has underutilized rearing capacity. Previous data suggest that fertilization benefited the lake and its sockeye stock (Hyatt and Stockner 1985). Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on better information on current escapements and on current growth and survival of juvenile sockeye (Table 7). The lake has a large population of *Chaoborus* sp., which may reduce its sockeye rearing capacity. Further, the lake's low pH of 5.70 is within the range that could deleteriously affect stock productivity (Rombough 1982), and this should also be investigated prior to further enhancement efforts.

Curtis Lake

Curtis Lake is located on Pitt Island, approximately 100 km south of Prince Rupert. It drains via a short stream into Principe Channel. Monthly limnological sampling was carried out from 1979-1983 and the lake was fertilized from 1980-1985 (Stockner and Shortreed 1985). It has a surface area of 3.0 km² and a mean depth of 34 m (Table 1). The area receives high annual precipitation, resulting in an estimated water residence time of only 0.6 yr. Curtis Lake stratified strongly during the years it was sampled, with an average epilimnetic temperature of 13.3°C and an average thermocline depth of 8.3 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 6.0 m (Table 2). The lake was very poorly buffered (average total alkalinity was only 1.0 mg $CaCO_3$/L) and was quite acidic, with an average pH of 5.80 during unfertilized years. The lake was highly oligotrophic and had low spring overturn concentrations of both total phosphorus (2.3 µg/L) and nitrate (27 µg N/L) (Table 3). Under unfertilized conditions, seasonal average chlorophyll concentration was 1.24 µg/L and PR averaged 103 mg $C \cdot m^{-2} \cdot d^{-1}$ (Shortreed and Stockner 1981). Zooplankton biomass was also low, averaging only 80 mg dry wt/m² (Table 4) (Rankin and Radziul 1986). Fertilization increased phytoplankton biomass and production in Curtis Lake substantially, with seasonal average chlorophyll of 4.02 µg/L, a PR_{mean} of 153 mg $C \cdot m^{-2} \cdot d^{-1}$, and average zooplankton biomass of 166 mg dry wt/m² (Table 4). Average smolt weight from Curtis Lake was 1.1 g in 1979, an unfertilized year, and increased 2.5-fold to an average of 2.8 g in the following two fertilized years (Hyatt and Stockner 1985). Available sockeye escapement data to Curtis Lake indicates that spawner numbers have averaged 4,500 since the 1980's, although several years of higher (>7,000) escapements were recorded in the 1970's. However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The PR model prediction of optimum escapement to unfertilized Curtis Lake is 10,000, suggesting that it currently has underutilized rearing capacity. Previous data suggest that fertilization benefited the lake and its sockeye stock (Hyatt and Stockner 1985). Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on better information on current escapements and on current growth and survival of juvenile sockeye (Table 7). Further, the lake's low pH of 5.80 is within the range that could deleteriously affect stock productivity (Rombough 1982), and this should also be investigated prior to further enhancement efforts.

Devon Lake

Devon Lake is located on Pitt Island, approximately 100 km south of Prince Rupert. It drains via a short stream into Principe Channel. Monthly limnological sampling was carried out in 1979 and 1980 and the lake was fertilized in 1980, 1984, and 1985 (Stockner and Shortreed 1985). It has a surface area of 1.8 km² and a mean depth of 29 m (Table 1). The area receives high annual precipitation, resulting in an estimated water residence time of only 1.3 yr. Devon Lake stratified strongly during the years it was sampled and had an average thermocline depth of 7.6 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 5.8 m (Table 2). The lake was very poorly buffered (average total alkalinity was only 0.7 mg $CaCO_3$/L) and was quite acidic, with an average pH of 5.60 during unfertilized years. The lake was highly oligotrophic and had low spring overturn concentrations of both total phosphorus (2.3 µg/L) and nitrate (20 µg N/L) (Table 3). Under unfertilized conditions, seasonal average chlorophyll concentration was 1.79 µg/L and PR averaged 103 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$ (Shortreed and Stockner 1981). Zooplankton biomass was also low, averaging only 77 mg dry wt/m² (Rankin and Radziul 1986; Table 4). Fertilization increased phytoplankton biomass and production in Devon Lake substantially, with seasonal average chlorophyll of 4.57 µg/L, a PR_{mean} of 160 mg $C{\cdot}m^{-2}{\cdot}d^{-1}$, and average zooplankton biomass of 108 mg dry wt/m² (Table 4). Average smolt weight from Devon Lake averaged 2.6 g in unfertilized years and were 66% higher (4.4 g) in 1980, when the lake was fertilized (Table 5; Hyatt and Stockner 1985). Available sockeye escapement data to Devon Lake indicates that spawner numbers have averaged 3,100 since the 1980's (Table 6). However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The PR model prediction for optimum escapement to unfertilized Devon Lake is 6,000, suggesting that it currently has underutilized rearing capacity. Previous data suggest that fertilization benefited the lake and its sockeye stock (Hyatt and Stockner 1985). Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on better information on current escapements and on current growth and survival of juvenile sockeye (Table 7). Further, the lake's low pH of 5.60 is within the range that could deleteriously affect stock productivity (Rombough 1982), and this should also be investigated prior to further enhancement efforts.

Eden Lake

Eden Lake is located on Graham Island of the Queen Charlotte Islands. It drains via the Naden River into Naden Harbour. Monthly limnological sampling was carried out in 1982 and

1983 and the lake was fertilized from 1979-1985 (Stockner and Shortreed 1985). No comparable data for unfertilized years are available, and all data presented here are from fertilized years. The lake has a surface area of 5.9 km² and a mean depth of 43 m (Table 1). The area receives high annual precipitation, resulting in an estimated water residence time of only 0.9 yr. Eden Lake stratified strongly during the years it was sampled and had an average thermocline depth of 13.7 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 4.4 m (Table 2). The lake was slightly acidic and had an average pH of 6.60. It had low spring overturn total phosphorus concentrations of 2.2 µg/L, but spring nitrate was relatively abundant (50 µg N/L) (Table 3). Seasonal average chlorophyll concentration was 1.63 µg/L and average zooplankton biomass was 612 mg dry wt/m² (Table 4). Smolts were relatively large, with an average weight of 4.3 g (Hyatt and Stockner 1985). Available sockeye escapement data to Eden Lake indicates that spawner numbers have averaged 2,500 over the past 10 yr (Table 6). However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The lack of unfertilized data makes it impossible to assess benefits of the previous fertilization. Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on obtaining better and more current data on escapements, on growth and survival of juvenile sockeye, on the plankton community, and on trophic status (Table 7).

Fred Wright Lake

Fred Wright is a small (surface area=3.9 km²) lake with a mean depth of 18 m (Table 1). It is located west of Meziadin Lake in the Nass River drainage basin. Limnological (n=5) and limnetic fish (n=2) surveys were carried out in 1978 (Stockner and Shortreed 1979; Simpson et al. 1981). The lake had a well-developed seasonal thermocline at an average depth of 7.0 m, but epilimnetic temperatures did not exceed 17°C (Table 2). It had a cool hypolimnion and clear water, with an average euphotic depth of 9.7 m. In general, Fred Wright Lake provided an excellent physical environment for juvenile sockeye. Epilimnetic nitrate concentrations were 1.0 µg N/L at the first sampling date in early June (Table 3). The seasonal average chlorophyll concentration of 1.75 µg/L and the PR_{mean} of 132 mg $C \cdot m^{-2} \cdot d^{-1}$ puts the lake in the middle to upper range of oligotrophy (Table 4). Zooplankton were relatively abundant, averaging 768 mg dry wt/m², and *Daphnia* made up a substantial portion of the community (Rankin and Ashton 1980). Juvenile sockeye density was relatively high (4,000/ha in the fall of 1978) and fry averaged 3.1 g (Simpson et al. 1981) (Table 5). Fred Wright is a relatively productive lake that can sustain a substantial sockeye population (estimated escapements in 1977 were 20,000). Predicted optimum escapements from the PR model is 17,000 spawners and in the 1990's escapements averaged 7,100 (Table 6). These data suggest that in most years the lake has underutilized rearing capacity, and increased fry recruitment would result in increased smolt production (Table 7).

Ian Lake

Ian Lake is located on Graham Island of the Queen Charlotte Islands. It drains via the Ain River into Masset Inlet. Monthly limnological sampling was carried out in 1982 and 1983 and the lake was fertilized from 1979-1983 (Stockner and Shortreed 1985). No comparable data for unfertilized years are available, and all data presented here are from fertilized years. With a surface area of 20 km², Ian is the largest lake in the Queen Charlotte Islands. It has a mean depth of 50 m and an estimated water residence time of 1.1 yr (Table 1). Ian Lake stratified strongly during the years it was sampled, with an average epilimnetic temperature of 14.3°C and an average thermocline depth of 13.2 m. It was strongly dystrophic and the organic stain resulted in an average euphotic zone depth of only 3.8 m (Table 2). The lake was acidic and had an average pH of 6.10. It had a low spring overturn total phosphorus concentration of 2.2 µg/L and a spring nitrate concentration of 33 µg N/L (Table 3). Seasonal average chlorophyll concentration was 1.10 µg/L and average zooplankton biomass was 605 mg dry wt/m² (Table 4). Smolts were unusually large, with an average weight of 6.8 g (Hyatt and Stockner 1985). Available sockeye escapement data to Ian Lake indicates that spawner numbers have averaged 1,000 since the mid-1980's (Table 6). However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. Nevertheless, given these escapements and the lake's relatively large size (20 km²), it is probable that there is substantial underutilized rearing capacity. The lack of unfertilized data makes it impossible to assess benefits of the previous fertilization. Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on obtaining better and more current data on escapements, on growth and survival of juvenile sockeye, on the plankton community, and on trophic status (Table 7).

Johanson Lake

Johanson Lake is located a short distance east of Sustut Lake and drains via the Sustut River into the Babine River, approximately 60 km north of Hazelton. It is the furthest upstream, the most northerly, and is located at the highest elevation of all Skeena system sockeye nursery lakes (Table 1). Limnological data from Johanson Lake were collected four times from June to October of 1994 and limnetic fish data were collected on one occasion in August of the same year (Shortreed et al. 1998). The lake has a mean depth of 16 m and at the time of sampling, had a cool, relatively deep (10.0 m) epilimnion and an average euphotic zone depth of 21.4 m (Table 2). Its high elevation (1,444 m) resulted in a short growing season (isothermal conditions lasted until late June). Johanson Lake was ultra-oligotrophic, with very low nutrient concentrations and low PR (Tables 3 and 4). Along with Sustut Lake, it had the lowest zooplankton biomass (17 mg dry wt/m²) of any Skeena system sockeye nursery lake. Small bosminids were the most common zooplankton. Sockeye stomachs were only 25% full and contents consisted mainly of insects. Limnetic fish densities were low and were almost exclusively sockeye fry. Age-1 sockeye made up an unusually high 10% of the population. These age-1 fish had an average size of only 2.4 g, which was smaller than age-0 sockeye in some of the more productive Skeena lakes (Table 5). Average escapement was 20% of the predicted optimum of 3,000 (Table 6). These data suggest that Johanson Lake could support a modest increase in sockeye recruitment, but its short growing season and ultra-oligotrophic status make it a less than ideal rearing environment. It is highly probable that fertilization would increase productivity and benefit juvenile sockeye in the lake (Table 7).

Kitlope Lake

Kitlope Lake is situated near the head of Gardner Canal on B.C.'s north coast and is located within the Kitlope Heritage Conservancy Protected Area. The lake was sampled monthly from 1978-1980 and was fertilized from 1979-1985 (Stockner and Shortreed 1979; Stockner et al. 1993). It has a surface area of 12 km² and a mean depth of 86 m (Table 1). Substantial flows from the cold and glacially turbid Tezwa River enter the upper end of the lake. This resulted in an estimated water residence time of only 0.5 yr, a cool epilimnion (seasonal average surface temperatures were 10.5°C), unstable thermal stratification, and an average euphotic zone depth of 7.6 m (Table 2). The lake has a riverine circulation pattern and the high flows into the lake combined with the shallow lake outlet result in daily epilimnetic flushing rates in summer ranging from 15-250% (Stockner et al. 1993). As a result of this rapid flushing of the epilimnion and low nutrient loading (spring overturn concentrations were 1.5 µg/L for total phosphorus and 64 µg N/L for nitrate), the lake was ultra-oligotrophic (Table 3). At the time of sampling, Kitlope Lake was slightly acidic (average pH=6.22) and poorly buffered, with a total alkalinity of only 1.6 mg $CaCO_3$/L. Seasonal average chlorophyll concentration was 0.55 µg/L, among the lowest ever recorded for a B.C. sockeye nursery lake (Table 4). Zooplankton biomass was also very low, averaging only 54 mg dry wt/m². Despite the fast epilimnetic flushing, both phytoplankton and zooplankton biomass increased in fertilized years. Sockeye fry averaged 2.1 g in an unfertilized year and increased 2.5-fold to an average of 5.2 g in two fertilized years (Hyatt and Stockner 1985; Table 5). The PR model prediction for optimum escapement to Kitlope Lake is 22,000 (Table 6). Over the past 10 yr, escapements have averaged 14,000, but given the visual methods used and the poor visibility in the Tezwa River, these estimates are tentative. If escapement estimates are accurate, the lake has some underutilized rearing capacity and earlier data indicates fertilization would be beneficial (Table 7).

Kitsumkalum Lake

Kitsumkalum Lake (also called Kalum Lake) is located 30 km north of Terrace and discharges via the Kitsumkalum River into the Skeena River near Terrace. Limnological data from Kitsumkalum Lake were collected once monthly from May to October (n=6) in 1994 and limnetic fish data were collected on one occasion in the fall of 1994 (Shortreed et al. 1998). The lake had a cool, deep epilimnion and an extensive hypolimnion but it was glacially turbid, with an average euphotic zone depth of only 3.8 m (Table 2). The high light attenuation resulted in Kitsumkalum Lake having the lowest PR_{mean} (33 mg $C \cdot m^{-2} \cdot d^{-1}$) ever recorded for a B.C. sockeye nursery lake and average chlorophyll concentrations of only 0.6 µg/L (Table 4). Zooplankton biomass was also low (97 mg dry wt/m²) and consisted mainly of diaptomid copepods. Consequently, sockeye stomachs were only 20% full and contained mainly diaptomids. Fall sockeye fry averaged only 1.6 g even though limnetic fish density was very low (Table 5). The lake is a relatively poor rearing environment and current sockeye escapements average only 3,300, well below the predicted optimum of 20,000 (Table 6). While an increased recruitment would most likely increase subsequent smolt production, expected gains would be tempered by low food supply. Lake fertilization would be of limited benefit because of light limitations associated with turbidity and a deep epilimnion (Table 7).

Kitwanga Lake

Kitwanga Lake (also called Kitwancool Lake) is located 40 km west of Hazelton and discharges via the Kitwanga River into the Skeena River. Limnological data from Kitwanga Lake were collected once monthly from May to October (n=6) of 1995 and limnetic fish data were collected once in the fall of 1995 (Shortreed et al. 1998). Kitwanga Lake is shallow, with a mean depth of only 5.0 m (Table 1). At the time of sampling, it had a prolonged period of strong thermal stratification with an average thermocline depth of 5.7 m (Table 2). Consequently, epilimnetic temperatures exceeding 18°C extended to lake bottom for up to 30% of the lake's total area during a four to six week period in mid-summer of 1995. Kitwanga Lake was relatively clear and the euphotic zone encompassed the entire water column in most areas of the lake. This warm, clear epilimnion and an average spring overturn total phosphorus of 10.8 µg/L resulted in Kitwanga Lake having one of the higher photosynthetic rates (PR_{mean}=265 mg $C \cdot m^{-2} \cdot d^{-1}$) ever recorded for a B.C. sockeye nursery lake (Tables 3 and 4). Average macrozooplankton biomass was high (1,770 mg dry wt/m²) and *Daphnia* made up 63% of the total. With high production and strong thermal stratification, summer oxygen concentrations become very low in the lake's hypolimnion (McConnell and Brett 1946; M. Cleveland, Gitanyow Fisheries Authority, personal communication). Therefore, for a portion of each growing season, there is no deep, cold-water refuge for sockeye and optimum temperatures for growth and predator avoidance are exceeded. Despite the abundant food supply and low limnetic fish density, our trawl data indicate fall sockeye fry averaged only 2.4 g (Table 5). However, this average was based on only four fish which possibly were kokanee. More recent data indicate that Kitwanga smolts are very large (ca. 18 g) (M. Cleveland, Gitanyow Fisheries Authority, personal communication). Present and historic sockeye production from Kitwanga Lake is far below the optimum predicted by the PR model. Average escapements of 400 sockeye are substantially less than the predicted optimum escapement of 75,000 (Table 6). Spawning ground capacity may also be substantially less than could support this predicted optimum (D. Peacock, Fisheries and Oceans Canada, personal communication). Further work is needed to identify factors limiting sockeye production in this system, which besides fry recruitment may include spawning ground quality and the lake's physical environment (Table 7). Given the high productivity and abundant *Daphnia* community, lake fertilization would be of little benefit.

Lakelse Lake

Lakelse Lake is located 15 km south of Terrace and discharges via the Lakelse River into the Skeena River approximately 10 km downstream of Terrace. It is a popular recreational and residential area. Limnological data from Lakelse Lake were collected once monthly from May to October (n=6) in 1994 and limnetic fish data were collected once in the fall of 1994 (Shortreed et al. 1998). The lake has a surface area of 13 km^2 and a mean depth of only 8.0 m (Table 1). There is a small (ca. 2.5 km^2) area in the southern portion of the lake having depths >15 m. For a relatively small lake, Lakelse had a deep (13.5 m) epilimnion and weak thermal stratification, indicating that windy conditions occur frequently (Table 2). The average euphotic zone depth was 7.7 m. Approximately 80% of the lake's total area was isothermal during the growing season and the euphotic zone comprised the entire water column over 48% of the lake's area. Spring overturn total phosphorus concentrations of 5.1 µg/L placed it in the mid-range of oligotrophy (Table 3). Spring overturn nitrate concentrations were low (31 µg N/L) and epilimnetic nitrate was depleted for much of the growing season. The average chlorophyll concentrations of 1.38 µg/L also indicated the lake is in the mid-range of oligotrophy (Table 4). *Daphnia* comprised only 9% of the total average macrozooplankton biomass of 718 mg dry wt/m^2. Despite this, *Daphnia* comprised >90% of the diet of sockeye fry and sockeye stomach fullness was 100%. Juvenile sockeye densities were low (fall fry=311/ha) in 1994 and their average weight of 6.1 g was larger than those from most B.C. sockeye nursery lakes (Table 5). Lakelse Lake appears to be an effective rearing area for sockeye fry with an abundant food supply. In 1994 sockeye fry biomass was only one-half of the maximum biomass predicted by the PR model and average escapements of 4,900 are substantially less than the predicted optimum escapement of 33,000 (Table 6). Potential competitors (stickleback and mysids) were present in the lake but the degree of competition (and consequent reduction in productive capacity) is unknown. Increasing fry recruitment would be the most effective way of enhancing this stock, but given the currently low *Daphnia* biomass, careful monitoring of sockeye growth rates and zooplankton community structure would be required (Table 7).

Lowe Lake

Lowe Lake is small (surface area=3.7 km^2), fast flushing (water residence time=0.2 yr), and has a mean depth of 25 m (Table 1). It is located on Grenville Channel approximately 90 km southeast of Prince Rupert. The lake discharges over a falls which drop directly into

Lowe Inlet, and upstream fish passage is restricted to extreme high tides (Simpson et al. 1981). Monthly limnological surveys were carried out on the lake from 1978-1981 and a limnetic fish survey was done in September of 1978 (Stockner and Shortreed 1979; Shortreed and Stockner 1981; Simpson et al. 1981). The lake was fertilized from 1979-1982. At the time of sampling, the lake had a stable seasonal thermocline and the average depth of the epilimnion was 8.3 m (Table 2). As with many other coastal B.C. lakes, Lowe Lake was organically stained and acidic (mean pH=5.70). Mean euphotic zone depth was 7.6 m. At spring overturn, average concentration of total phosphorus was 1.2 µg/L and average concentration of nitrate was 23 µg N/L (Table 3). During summer, nitrate concentration declined to about 4 µg N/L but did not reach depletion (<1 µg N/L). Chlorophyll concentration (mean=1.22 µg/L), photosynthetic rates (PR_{mean}=107 mg $C\cdot m^{-2}\cdot d^{-1}$), and the low nutrient loading all indicate the lake is oligotrophic (Table 4). Macrozooplankton biomass averaged only 180 mg dry wt/m² and the small cladoceran *Bosmina longispina* was dominant. Average size of sockeye fry in the fall of 1978 was only 1.2 g (n=6), even though density was low (150/ha) (Simpson et al. 1981; Table 5). Nutrient additions increased phytoplankton and zooplankton biomass (Shortreed and Stockner 1981), although it is unclear why photosynthetic rates appeared to be lower during fertilized years (Table 4). During two fertilized years average smolt size was 3.7 g (Hyatt and Stockner 1985). Since it is unlikely that the 1.2 g fall fry from 1978 year would have grown to ca. 3 g smolts, it appears fertilization substantially increased juvenile sockeye growth rates. Since the late 1980's sockeye escapements to Lowe Lake have averaged 3,200 (range: 1,000-6,000), substantially lower than the PR model predicted optimum of 13,000 (Table 6). Additional data on recent escapements, on fish passage difficulties at the lake outlet, and on current status of juvenile sockeye are needed, but the earlier data indicate that Lowe Lake sockeye benefited from fertilizer applications (Table 7).

Mercer Lake

Mercer Lake is located on the Queen Charlotte Islands in the V.J. Krajina Ecological Reserve. It drains via a short (<2 km) stream into Port Chanal on the west coast of Graham Island. Limnological sampling was carried out in 1979 (n=4) and 1980 (n=3) and the lake was fertilized in 1979 (Costella et al. 1982). Mercer Lake has a surface area of only 1.2 km², a mean depth of only 15 m, and high hydraulic loading results in an estimated water residence time of only 0.1 yr (Table 1). It is dystrophic and in the years it was sampled the organic stain resulted in an average euphotic zone depth of only 6.1 m (Table 2). The lake was acidic and had an average pH of 5.30 when it was unfertilized and 6.00 in the fertilized year. Nutrient loading was low, with a spring overturn total phosphorus concentration of only 2.0 µg/L and a spring nitrate concentration of only 13 µg N/L (Table 3). Seasonal average chlorophyll concentration was 2.50 µg/L and average zooplankton biomass was 225 mg dry wt/m² (Table 4). During the fertilized year chlorophyll concentration was lower (1.66 µg/L) and the limited available data provide no explanation for this. Available sockeye escapement data to Mercer Lake indicates that spawner numbers have averaged 2,100 since the mid-1980's (Table 6). However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. The limited available data makes it impossible to assess benefits of the previous fertilization. Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on obtaining better and more current data on escapements, on growth and survival of juvenile sockeye, on plankton communities, and on trophic status (Table 7).

Meziadin Lake

Meziadin Lake is the largest sockeye producer in the Nass River system and is located 140 km northwest of Hazelton. It has a surface area of 36 km² and a mean depth of 45 m (Table 1). Limnological data were collected monthly (May to October) in 1978 and 1979 (Stockner and Shortreed 1979; Shortreed and Stockner 1981). Limnetic fish surveys (n=2) were carried out in 1978 (Simpson et al. 1981), in the early 1990's (McCreight et al. 1993), and in more recent years by consultants for the Nisga'a Tribal Authority. Glacially turbid inflows enter the lake at its northwestern end. During the sampling period, the lake developed a relatively weak seasonal thermocline at a depth of 5.4 m (Table 2). Surface temperatures were <16°C for most of the growing season and tended to be slightly higher near the southeastern (outlet) end, furthest from the glacial inflows. Despite the glacial tributaries, the lake was relatively clear, with seasonal average euphotic zone depths of 9.6 m near the head of the lake and 12.2 m near the lake outlet. In general, at the time of the study Meziadin Lake provided an excellent physical environment for juvenile sockeye. The lake had an abundant nitrogen supply, with average spring overturn concentrations of 219 µg N/L, which are the highest yet recorded for a B.C. sockeye nursery lake (Table 3). Seasonal average nitrate concentrations were 131 µg N/L and minimal summer epilimnetic concentrations were 40 µg N/L. The seasonal average chlorophyll concentration of 1.46 µg/L and the PR_{mean} of 171 mg $C \cdot m^{-2} \cdot d^{-1}$ is similar to that found in Shuswap Lake and puts the lake in the middle to upper range of oligotrophy (Table 4). Zooplankton biomass averaged 516 mg dry wt/m², approximately mid-range for Skeena and Nass sockeye nursery lakes, and *Daphnia* made up a substantial portion of the community (Rankin and Ashton 1980). Size of juvenile sockeye fry in fall was small (mean=1.9 g), with fry densities of densities of 1,662/ha (Table 5). Meziadin is a relatively productive lake that currently supports a substantial sockeye population. The PR model predicts that optimum escapement to the lake at photosynthetic rates recorded in the late 1970's would be 207,000 adult spawners (Table 6). Since the late 1980's, escapements have averaged 228,000 and since 1970 have averaged 185,000. These data suggest that the lake's productive capacity is often fully utilized. Further information is needed on nutrient loading, on recent productivity, zooplankton, and juvenile sockeye growth, diet, and density before factors currently constraining Meziadin sockeye production can be determined (Table 7). Available data suggest that lake fertilization is an option worth exploring.

Morice Lake

Morice is a large (96 km²), deep (mean depth=100 m) lake located 85 km southeast of Terrace (Table 1). It drains via the Morice River into the Bulkley River near the community of Houston. Limnetic fish data from Morice Lake were collected in the fall of 1993 and limnological data were collected once monthly in 1978 and 1980 (Stockner and Shortreed 1979; Costella et al. 1982; Shortreed et al. 1998). These surveys indicated that Morice Lake had generally excellent physical conditions for juvenile sockeye, with a deep (19.8 m) euphotic zone, a cool epilimnion, and a large hypolimnion (Table 2). However, the lake was ultra-oligotrophic (spring overturn total phosphorus concentration was 1 µg/L) (Table 3). Despite low planktivore densities, zooplankton biomass was low (Table 4), resulting in very slow growth rates for sockeye fry. Age-0 fall fry captured in 1993 averaged only 0.8 g, among the smallest ever recorded for a B.C. sockeye nursery lake (Table 5). Sockeye stomachs were <30% full and contained mostly bosminids. A large proportion (ca. 90%) of adults returning to spawn in Morice Lake were off-spring of 2-year old smolts (Simpson et al. 1981). This provides further confirmation of the lake's low productivity and deficient food supply, since most sockeye require only one year of lake residence to grow large enough to smolt. Average escapements are only 20,700, but some of the highest recorded escapements of 25,000-41,000 have occurred in the late 1990's (Table 6). However, even these recent, record escapements are less than 20% of the predicted optimum escapement of 211,000 (Table 6). Morice Lake was fertilized in 1980 and responded positively, with a 35% increase in phytoplankton biomass and a 60% increase in zooplankton biomass (Stockner and Shortreed 1979; Costella et al. 1982). Morice Lake is an excellent candidate for nutrient additions and the recent higher escapements make it even more favorable (Table 7). Given the lake's large size, there is the potential for large increases to its sockeye stock.

Morrison Lake

Morrison Lake has a surface area of 13 km² and drains via the Morrison River into Morrison Arm of Babine Lake (Table 1). Limnological data were collected from May to October (n=7) of 1995 and limnetic fish data were collected once in the fall of 1995 (Shortreed et al. 1998). At the time of sampling, the lake provided a good physical habitat for sockeye fry with a mean depth of 21 m and a mean epilimnetic temperature of 13.5°C. It had a relatively shallow mean thermocline depth of 6.2 m and its organically stained water resulted in an average euphotic zone depth of only 4.2 m (Table 2). The lake's nutrient concentrations and phytoplankton biomass placed it in the upper range of oligotrophy (spring overturn total phosphorus was 8.5 µg/L) (Table 3) , but the rapid light attenuation limited PR_{mean} to 108 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). The zooplankton community was dominated by copepods, with the calanoid copepod *Epischura* sp. the most important food item for juvenile sockeye. Age-0 fall sockeye fry were relatively large (4.3 g), indicating an adequate food resource for current fish densities (Table 5). Sockeye densities were low, as were numbers of other limnetic species, which consisted primarily of whitefish but also included redside shiners and sculpins. Recent escapements to Morrison Lake have averaged only 5,700, less than 15% of the predicted optimum escapement (Table 6). However, Brett (1952) suggested that spawning ground capacity was limited in this system, and is likely not sufficient for the predicted optimum escapement of 48,000. Increased fry recruitment through increased spawner numbers and improvements to spawning grounds (e.g. removal of obstructions such as beaver dams) would be the most effective way to enhance/restore this stock (Table 7). The feasibility of carrying out fry outplants should also be investigated.

Simpson Lake

Simpson Lake is located near Grenville Channel on the central coast and drains into Lowe Lake via Simpson Lake Creek. This creek had a partial blockage to adult sockeye which was removed in 1964. At this time it is not known if the lake is used as a sockeye rearing area, although kokanee have been captured in the lake. Monthly limnological surveys were carried out on the lake in 1978 and in 1982 (Stockner and Shortreed 1979; Costella et al. 1983). A limnetic fish survey was done in September of 1978 (Simpson et al. 1981). Simpson Lake has a surface area of 8.7 km² and a mean depth of 57 m (Table 1). At the time of sampling, the lake had a stable seasonal thermocline with an average thermocline depth of 11.1 m (Table 2). As with many other coastal B.C. lakes, Simpson Lake is organically stained and had a mean euphotic zone depth of 7.2 m. At spring overturn, average concentration of total phosphorus was 1.0 µg/L and of nitrate was 26 µg N/L (Table 3). During summer, epilimnetic nitrate was depleted (<1 µg N/L). Chlorophyll concentrations (mean=1.12 µg/L), PR_{mean} (64 mg $C \cdot m^{-2} \cdot d^{-1}$), and the low nutrient loading all indicate the lake is highly oligotrophic (Table 4). The zooplankton community was dominated by cyclopoid copepods and the small cladoceran *Bosmina longispina* (Rankin and Ashton 1980). Zooplankton biomass averaged only 387 mg dry wt/m² and the lake had a substantial population of *Chaoborus* sp. In the 1978 limnetic fish survey, only two *O. nerka* were caught and they may have been kokanee (Simpson et al. 1981). While the PR model predicts an optimum escapement of 19,000, additional data on recent escapements, on possible fish passage difficulties at the lake outlet, and on current status of juvenile sockeye are needed before factors potentially limiting sockeye production can be determined (Table 6,7). If sockeye currently do not use the lake as a nursery area, fry outplants may be useful in creation of a new run.

Stephens Lake

Stephens Lake is a small (surface area=1.9 km²), shallow (mean depth=11m) lake located 3 km downstream of Swan Lake (Table 1). The outlet of Stephens Lake enters the Kispiox River a short distance (<5 km) downstream. Limnological sampling was carried out once monthly from May to October in 1978 (Stockner and Shortreed 1979) and limnetic fish were sampled in July and October of the same year (Simpson et al. 1981). The lake exhibited pronounced thermal stratification with a strong thermocline at a depth of 4.8 m (Table 2). Maximum surface temperatures did not exceed 18°C. Average euphotic zone depth was 13.1 m. The lake had low nitrate concentrations, with spring overturn values of 8.0 µg N/L and a seasonal average of only 3.1 µg N/L (Table 3). Seasonal average phytoplankton biomass (chlorophyll) was 1.45 µg/L (Table 4). Although there are no data on phosphorus loading and photosynthetic rates from Stephens Lake, it appears to be oligotrophic and is most likely nutrient-limited. Macrozooplankton biomass was relatively high (1,034 mg dry wt/m²), as was *Daphnia* abundance (Rankin and Ashton 1980). Planktivore densities in fall were 250/ha and their average size was 3.1 g, indicating an adequate food supply (Table 5). In 1978, Stephens Lake appeared to be an underutilized nursery area, but more recent data on escapements and juvenile sockeye numbers and growth are required to determine if this continues to be the case. Estimated numbers of sockeye spawners to the Swan/Club/Stephens system averaged 7,700, but the relative importance of the lakes as nursery areas is unknown (Table 6). Additional data on sockeye utilization of Stephens Lake and its trophic status are needed before appropriate enhancement or restoration initiatives can be recommended (Table 7).

Sustut Lake

Sustut Lake drains via the Sustut River into the Babine River approximately 60 km north of Hazelton. Other than nearby Johanson Lake, Sustut is the furthest upstream, the most northerly, and is located at the highest elevation (1,301 m) of all Skeena system nursery lakes (Table 1). Limnological data from Sustut Lake were collected from June to October (n=4) in 1994 and limnetic fish data were collected in August of 1994 (Shortreed et al. 1998). The lake's northerly location and high elevation resulted in a cool epilimnion (mean temperature=11.1°C) and a short growing season (Tables 1 and 2). Sustut Lake is shallow, with a mean depth of 6.0 m and a maximum depth of only 19 m. The euphotic zone extended to the lake bottom in most areas of the lake. During the sampling period, average total phosphorus concentrations were 6.5 µg/L but the lake had a severe nitrogen deficiency throughout the growing season (at no time were nitrate concentrations greater than our analytical detection limit of 1 µg N/L) (Table 3). As a result, Sustut Lake was ultra-oligotrophic, with a low PR_{mean} of 88 mg $C \cdot m^{-2} \cdot d^{-1}$, low chlorophyll concentrations (seasonal average=1.43 µg/L), and very low zooplankton biomass (seasonal average=17 mg dry wt/m²) (Table 4). Sockeye stomachs were only 25% full and contained mostly bosminids, suggesting an inadequate food supply. Limnetic fish densities were relatively high (1,779/ha) and were almost exclusively age-0 sockeye (Table 5). Fry were small (1.0 g), but the August sampling date makes it difficult to compare to other lakes. Recent escapements have been up to 50% of the PR model optimum of 5,000 (Table 6). Increasing fry recruitment to Sustut Lake would most likely increase smolt production, but given the lake's extreme oligotrophy and poor food supply, the most effective enhancement would be combining increased recruitment with lake fertilization (Table 7).

Swan Lake

Swan Lake is located approximately 140 km north of Terrace and discharges through Club and Stephens lakes into the Kispiox River. Limnological data from Swan Lake were collected from May to October (n=6) in 1978 and limnetic fish data were collected in 1978 and in 1995 (Stockner and Shortreed 1979; Simpson et al. 1981; Shortreed et al. 1998). Its physical environment was excellent for juvenile sockeye, with a 15.3 m euphotic zone depth, a stable cool epilimnion, and a large hypolimnion (Table 2). Nitrate was 15 μg N/L at spring overturn, averaged 8.1 μg N/L seasonally, and was depleted (<1 μg N/L) for a portion of the growing season (Table 3). The lake appeared to be oligotrophic and nutrient-limited, with a PR_{mean} of 93 mg $C \cdot m^{-2} \cdot d^{-1}$ and zooplankton biomass similar to that found in Quesnel Lake in the Fraser River system (Table 4). *Daphnia* were abundant relative to other northern interior lakes (Rankin and Ashton 1980) and during the most recent fish survey, sockeye stomachs were greater than 75% full, with *Daphnia* making up most of the stomach contents. In 1995, planktivore densities were 475/ha and more than 90% were age-0 sockeye (Table 5). However, despite a good physical environment, an abundant food supply, and low planktivore densities, Swan Lake fall fry averaged only 1.3 g. The earlier limnetic fish study (Simpson et al. 1981) reported that Swan Lake fall fry averaged only 1.0 g. Given the apparently good rearing conditions, it is unclear why Swan Lake sockeye fry do not exhibit higher growth rates. The majority of sockeye spawners to the Swan/Club/Stephens system of lakes spawn in Upper and Lower Club creek, and it is unknown which lake is the major nursery area. The low fry densities in Swan Lake suggest that its productive capacity is underutilized and that additional fry recruitment would increase smolt production, but reasons for the small fry size should be better understood before any enhancement or restoration is undertaken (Table 7).

Yakoun Lake

Yakoun Lake is located on Graham Island of the Queen Charlotte Islands. It drains via the Yakoun River into Masset Inlet. Monthly limnological sampling was carried out in 1982 and 1983 and the lake was fertilized from 1983-1985 (Stockner and Shortreed 1985). The lake has a surface area of 8.1 km², a mean depth of 39 m, and an estimated water residence time of 2.5 yr (Table 1). Yakoun Lake stratified strongly during the years it was sampled, with an average epilimnetic temperature of 14.4°C and an average thermocline depth of 7.8 m. It was dystrophic and the organic stain resulted in an average euphotic zone depth of 7.2 m during the unfertilized year (Table 2). The lake had a low spring overturn total phosphorus concentration of only 1 μg/L and spring nitrate concentration was 36 μg N/L (Table 3). Seasonal average chlorophyll concentration was 1.69 μg/L and average zooplankton biomass was 184 mg dry wt/m² (Table 4). In the fertilized year (1983) chlorophyll concentrations almost doubled to an average of 3.28 μg/L but zooplankton biomass decreased to 140 mg dry wt/m². Available sockeye escapement data to Yakoun Lake indicates that spawner numbers have averaged 6,400 since the mid-1980's. However, given the visual methods used and the poor visibility in the organically stained water, these estimates are tentative. Whether the fertilization program is renewed or whether fry recruitment is supplemented should be dependent on obtaining better and more current data on escapements, on growth and survival of juvenile sockeye, on the plankton community, and on trophic status (Table 7).

South Coast

Great Central Lake

Great Central Lake is located approximately 15 km west of the town of Port Alberni and discharges into the upper end of Alberni Inlet via the Stamp and Somass rivers. In the late 1960's and early 1970's it was the site of the original whole-lake fertilization experiment which documented the efficacy of the technique for enhancing sockeye salmon in B.C. lakes (Lebrasseur et al. 1978). Great Central Lake has been fertilized every year since 1977 and the only available unfertilized data are from three years in the mid-1970's (Lebrasseur et al. 1978). Detailed limnological sampling was carried out from 1977-1985 (Stockner and Shortreed 1985), with less detailed sampling being carried out in most years since. The lake's limnetic fish community has been sampled every year for most of the last 30 yr (Hyatt and Leudke 1999). It has a surface area of 51 km² and is one of the deepest lakes in B.C., with a mean depth of 212 m (Table 1). In the years it was sampled, Great Central Lake had prolonged (May to October), strong, thermal stratification and an average thermocline depth of 9.9 m (Table 2). In summer, epilimnion temperatures often exceeded 20°C for an extended period. The lake was clear, with an average euphotic zone depth of 16.2 m. Even when fertilized, the lake is oligotrophic, with low epilimnetic summer nutrient concentrations (mean epilimnetic total phosphorus concentration averaged 1.8 µg/L) and average epilimnetic chlorophyll concentrations of 1.06 µg/L (Tables 3,4). Seasonal average zooplankton biomass was variable but averaged 435 mg dry wt/m². Plankton community composition was also variable, with *Daphnia* comprising a substantial portion of total plankton biomass in some years and a very small proportion in others. Great Central sockeye comprise the major component of the Barkley Sound sockeye fishery and over the past 10 years, escapements to the lake have averaged 196,287 (Hyatt and Leudke 1999), close to the predicted optimum escapement of 212,000 (Table 6). Fertilizer applications have substantially increased Great Central sockeye numbers (Lebrasseur et al. 1978; Hyatt and Steer 1987). From a fisheries production perspective, the fertilization of Great Central Lake should continue, but from an experimental and assessment perspective, it would be beneficial to have several years of unfertilized conditions for comparative purposes (Table 7).

Henderson Lake

Henderson Lake is located on Vancouver Island and drains into Alberni Inlet via the Henderson River and Uchucklesit Inlet. In most years, the lake supports a substantial sockeye stock, with an average escapement of 36,000 (range: 3,000-120,000) (Hyatt and Leudke 1999). Henderson Lake was fertilized every year from 1976-1999. It was not fertilized in 2000 because of a very low escapement (4,412 spawners) in 1999. Limnological sampling was carried out at the lake monthly from early spring until late fall from 1977-1984 (Stockner and Shortreed 1985). Annual acoustic and trawl surveys have been carried out at the lake since 1977 (K. Hyatt, Fisheries and Oceans Canada, personal communication). As with most lakes located near the B.C. coast, Henderson Lake is warm monomictic and high annual precipitation results in rapid flushing rates (estimated water residence time is 1.3 yr) (Table 1). The lake is ectogenically meromictic, with a saline layer beginning at 45-50 m (Costella et al. 1980). Frequent intense rainfall in the fall and winter causes sudden freshets in Clements Creek, which is the major spawning tributary for Henderson sockeye. As a result, spawning grounds are unstable and egg-to-fry survival may be low relative to streams with more stable flows (Thorne and Ames 1987). Henderson Lake has a surface area of 15 km² and a mean depth of 109 m.

In the years it was sampled, Henderson Lake developed a stable seasonal thermocline (mean depth=15.9 m) and had a mean epilimnetic temperature of 14.1°C (Table 2). The average euphotic zone depth was 10.3 m. As with many coastal lakes, Henderson Lake was slightly acidic (mean pH=6.85) and was poorly buffered, with a total alkalinity of only 7.5 mg $CaCO_3$/L. No limnological data from unfertilized years are available for Henderson Lake. The average total phosphorus concentration during fertilized years was 3.2 µg/L (Table 2), indicating the lake is oligotrophic, but the average chlorophyll concentration of 2.52 µg/L and the PR_{mean} of 203 mg $C\cdot m^{-2}\cdot d^{-1}$ place it in the upper range of oligotrophy (Table 3). Average zooplankton biomass was 469 mg dry wt/m^2, relatively high for a coastal lake. The copepod *Diaptomus oregonensis* and the small cladoceran *Bosmina coregoni* were the dominant species (Rankin et al. 1979). Available data indicate that during fertilized years, both photosynthetic rates and zooplankton biomass are relatively high and the lake is an effective rearing area for juvenile sockeye. Restoration of Henderson sockeye would best be implemented through increasing fry recruitment by improving spawning ground conditions (e.g. stream stabilization, spawning channels) or by fry outplants. A sockeye hatchery has operated on Henderson Lake for several years and an evaluation of its effect on Henderson sockeye production should be carried out. Whether fertilization is warranted would best be determined by obtaining data on productivity, on the zooplankton community, and on limnetic fish for several unfertilized years (Table 7).

Hobiton Lake

Hobiton Lake is located in Vancouver Island's Pacific Rim National Park and drains into Nitinat Lake. It supports a relatively small sockeye stock which had an average escapement of 7,639 in the 1990's. Hobiton Lake was fertilized from 1977-1983 and from 1988-1998. Limnological sampling was carried out at the lake monthly from 1977-1985 (Stockner and Shortreed 1985) so only two years of unfertilized data (1984 and 1985) are available. Annual acoustic and trawl surveys have been carried out at the lake in most years since 1977 (K. Hyatt, Fisheries and Oceans Canada, personal communication). As with most lakes located near the B.C. coast, Hobiton Lake is warm monomictic and high annual precipitation results in rapid flushing rates (estimated water residence time is one year). The majority of Hobiton sockeye spawn in the lake itself and are, therefore, not as vulnerable to the unstable spawning ground conditions common to many coastal sockeye stocks. Hobiton Lake is small (surface area=3.6 km^2) and has a mean depth of 36 m (Table 1).

In the years it was sampled, Hobiton Lake developed a stable seasonal thermocline (mean depth=9.2 m) and had a mean epilimnetic temperature of 14.5°C (Table 2). The average euphotic zone depth was 10.8 m. As with many coastal lakes, Hobiton was slightly acidic and had an average pH of 6.6 (Stockner and Shortreed 1985). The lake is highly oligotrophic in unfertilized years, with spring overturn total phosphorus concentrations of only 1.5 µg/L and spring overturn nitrate concentrations of 31 µg N/L (Table 3). Epilimnetic nitrate was depleted (<1 µg N/L) for much of the growing season (Hardy et al. 1986). Plankton biomass was low and within the range often seen in oligotrophic coastal lakes, with mean epilimnetic chlorophyll concentrations of 1.22 µg/L and an average zooplankton biomass of 292 mg dry wt/m^2 (Table 4). The lake responded positively to fertilization, with a 51% increase in chlorophyll concentration and a 61% increase in zooplankton biomass. Utilizing data from a range of fertilized and unfertilized coastal lakes (including Hobiton Lake), Hyatt and Stockner (1985) reported that average smolt size increased 69% during fertilized years, strongly suggesting that Hobiton sockeye benefited from the fertilizer applications.

The Hobiton Lake sockeye stock is not large enough to produce a harvestable surplus for a commercial fishery, but substantial numbers are harvested in a native food fishery in Nitinat Lake. The fertilization program was stopped after 1998 because of a change in the method used for fertilizer applications (D. MacKinlay, Fisheries and Oceans Canada, personal communication). From 1977-1998 fertilizer was applied from an aircraft, so the lack of road access to Hobiton Lake was not a disadvantage. Starting in 1999, fertilizer was applied from boats, so road access became a prerequisite.

Kennedy Lake

Kennedy is a large (surface area=64 km²) lake located on Vancouver Island, 20 km east of the town of Tofino. It discharges via the Kennedy River into Tofino Inlet. The lake has two discrete basins (Main and Clayoquot arms) connected by a narrow (<300 m), shallow (<10 m) sill (Stockner and Shortreed 1988). Clayoquot Arm has a surface area of 17 km² and a mean depth of 51 m; Main Arm has a surface area of 47 km² and a mean depth of 27 m. As with most B.C. coastal lakes, the water residence time is short (1.1 year) (Table 1). Since the mid-1980's, sockeye escapements to Kennedy Lake have averaged only 11,000, which is a spawner density of <2/ha. However, as with many coastal lakes, the visual means used to obtain the escapement estimates leave considerable uncertainty. Detailed limnological sampling was carried out from 1977-1985. The lake's limnetic fish community was sampled in those years and for a number of years after (K. Hyatt, Fisheries and Oceans Canada, personal communication). Clayoquot Arm was fertilized from 1978-1984 and the Main Arm in 1979, 1980, 1985, and 1987-1989.

In the years it was sampled, Kennedy Lake had a stable thermocline from May to October and an average thermocline depth of 8.9 m (Table 2). Mean epilimnetic temperatures were a relatively warm 14.6°C and summer epilimnetic temperatures exceeded 20°C for extended periods in some years. In unfertilized basins and years, the lake had an average euphotic zone depth of 9.4 m. Kennedy Lake is highly oligotrophic, with spring overturn total phosphorus concentrations of only 1.5 µg/L and spring overturn nitrate concentrations of 28 µg N/L (Table 3). Seasonal average epilimnetic chlorophyll concentrations were 1.10 µg/L and PR_{mean} was 71 mg $C \cdot m^{-2} \cdot d^{-1}$ (Table 4). Zooplankton biomass averaged only 227 mg dry wt/m² when the lake was not fertilized. Zooplankton community composition was typical of highly oligotrophic coastal lakes, with dominant species being the small cladoceran *Bosmina coregoni* and the copepods *Cyclops bicuspidatus* and *Diaptomus oregonensis* (Rankin et al. 1979). Kennedy Lake responded strongly to fertilizer additions, with substantial increases in chlorophyll concentration (2.2-fold), photosynthetic rates (3.7-fold), and zooplankton biomass (1.6-fold) (Table 4). For several years in the early 1980's fertilizer applications at a low N:P ratio resulted in substantial blooms of the nitrogen-fixing cyanobacteria *Anabaena circinalis*, but use of a higher N:P ratio eliminated this bloom (Stockner and Shortreed 1988).

Kennedy Lake contains populations of both mysids (*Neomysis relicta*) and stickleback (*Gasterosteus aculeatus*), both of which may compete with juvenile sockeye (O'Neill and Hyatt 1987; Cooper et al. 1992). Despite the competitors, sockeye smolt size increased 30% from 2.0 g in 1977 to 2.6 g in 1978, the first year the lake was fertilized (Hyatt and Stockner 1985). This increase occurred despite a 60% increase in fish density from 2,025/ha in 1977 to 3,260/ha in 1978 (Hyatt and Stockner 1985). The data indicate that Kennedy Lake's plankton community and its juvenile sockeye responded positively to fertilizer additions. Predicted optimum escapement to unfertilized Kennedy Lake is 130,000 spawners, an order of magnitude higher than current escapements. However, this predicted optimum escapement needs to be adjusted downwards to account for competition with the lake's other planktivores (stickleback and mysids). Since even at low escapements sockeye growth rates in Kennedy Lake are very low, it is clear that restoration of Kennedy Lake sockeye requires lake fertilization as well as additional fry recruitment (Table 7). Other factors (e.g. overfishing, spawning ground instability) could be constraining Kennedy sockeye and these need to be better understood.

Muriel Lake

Muriel Lake is located approximately 1 km west of Clayoquot Arm of Kennedy Lake. It drains via a short (<2 km) stream into the Kennedy River about 3 km above Tofino Inlet. Limnological sampling was carried out on four occasions in 1983 (Nidle et al. 1984). The lake has a surface area of 1.5 km², a mean depth of 22 m, and an estimated water residence time of one year (Table 1). Muriel Lake had a warm epilimnion (average epilimnetic was 17.3°C) and a stable thermocline which had an average depth of only 4.8 m. The lake was organically stained and had an average euphotic zone depth of 5.6 m (Table 2). It had a low spring overturn total phosphorus concentration of 1.2 µg/L and a spring nitrate concentration of 29 µg N/L (Table 3). Epilimnetic nitrate was depleted (<1 µg N/L) for most of the growing season. Seasonal average chlorophyll concentration was 0.93 µg/L and average zooplankton biomass was 323 mg dry wt/m² (Table 4). The limited available sockeye escapement data to Muriel Lake indicates that spawner numbers have averaged 1,200 since the mid-1980's (Table 6). Available data suggest that Muriel Lake's productivity is strongly nutrient-limited. Whether lake fertilization or some other form of enhancement/restoration is warranted requires further and more recent data on escapements, on juvenile sockeye growth and survival, on plankton community structure, and on current trophic status (Table 7).

Sproat Lake

Sproat Lake is located approximately 10 km west of the town of Port Alberni and discharges into the upper end of Alberni Inlet via the Sproat and Somass rivers. It has a surface area of 41 km² and a mean depth of 59 m (Table 1). The lake has four distinct basins, with Taylor Arm (surface area=22 km²) making up 54% of the total lake area. The lake is heavily utilized for recreation and there are substantial numbers of residences around the three smaller arms. Sproat Lake sockeye are an important component of the Barkley Sound fishery, with returns second only to those of Great Central Lake. Over the past 10 years, escapements to Sproat Lake have been relatively consistent and have averaged 162,883 (range: 102,789-211,298) (Hyatt and Leudke 1999). Detailed limnological sampling was carried out from 1981-1986 (Shortreed and Stockner 1990). The lake's limnetic fish community has been sampled every year for most of the last 30 yr (Hyatt and Leudke 1999). Taylor Arm, the lake's largest basin, was fertilized in 1985 and for the first half of the growing season (May to July) in 1986.

In the years it was sampled, Sproat Lake had prolonged (May to October) strong thermal stratification and an average thermocline depth of 10.3 m. Mean epilimnetic temperatures were a warm 16°C (Table 2). As with nearby Great Central Lake, summer epilimnetic temperatures often exceeded 20°C for extended periods. The lake was clear, with an average euphotic zone depth of 20.2 m in unfertilized basins and years. It was highly oligotrophic, with spring overturn concentrations of total phosphorus of only 1.2 µg/L and spring overturn nitrate concentrations of 21 µg N/L (Table 3). Epilimnetic nitrate was depleted (<1 µg N/L) for much of the growing season. Average epilimnetic chlorophyll concentration was 0.60 µg/L and PR_{mean} was 84 mg $C \cdot m^{-2} \cdot d^{-1}$. Average zooplankton biomass was 285 mg dry wt/m² in unfertilized basins and years (Table 4).

The lake responded positively to fertilization, with an 80% increase in chlorophyll concentration, a 2.2-fold increase in photosynthetic rate, and an 2.1-fold increase in zooplankton biomass (Table 4). Given the similarities between limnological characteristics of Sproat and Great Central lakes, Sproat sockeye likely benefited from the fertilization as well. Given that current escapements to Sproat Lake are substantial (40% higher than the predicted optimum escapement), it is probable that the lake's rearing capacity is fully utilized in most years (Table 6). All these factors indicate that Sproat Lake is an excellent candidate for fertilization. However, the lake's popularity as a residential and recreational area suggests that, as with Shuswap Lake, fertilizer applications may be socially unacceptable (Table 7).

IV. Conclusions and Summary by DFO Management Area

Conclusions

In this report we present conclusions and recommended actions developed from the data summarized here (Table 7). The amount and quality of data available for each lake varies substantially, and significant information gaps exist for many of the lakes. On some lakes, insufficient data are available to make specific recommendations, and in Table 7 we have summarized the additional data required. On other lakes, more data are available, and we have made tentative suggestions about appropriate courses of action, which could be validated by filling the identified information gaps (Table 7, numbers not in bold). On yet other lakes, sufficient data are available to make specific recommendations (Table 7, bold numbers). These recommendations are developed from assessments of a wide variety of physical, chemical, and biological variables. While the data are quantitative, the relationship(s) between some variables and their relative importance to the a lake's enhancement potential have not been quantified. The recommendations therefore result from a combination of quantitative predictions (e.g. PR model predictions of optimum escapement) and qualitative assessments of some trophic interactions (e.g. sockeye fry size and density in relation to zooplankton biomass and community composition).

Summary by Area

B.C. Interior

In this report we present data summaries from 17 lakes in the B.C. Interior area, all of which are in the Fraser River drainage basin. Several of these lakes are among the largest in B.C., both in surface area and in current numbers of sockeye produced. With some exceptions, the lakes are effective sockeye nursery areas, with good physical environments and zooplankton communities dominated by large cladocerans such as *Daphnia*. Most (Chilko Lake is an exception) are more productive than sockeye nursery lakes located in the other four areas in this report.

Escapements to the largest producers (Chilko, Quesnel, and Shuswap lakes) have reached or exceeded their respective rearing capacities in some recent years (Hume et al. 1996). In recent years, large escapements to Chilko Lake have resulted in reduced smolt production as the lake's rearing capacity was exceeded. A previous fertilization program on Chilko Lake was successful in increasing size and survival of juvenile sockeye even at these high escapements (Bradford et al. 2000). Quesnel Lake has been identified as an excellent candidate for fertilization, with a potential for production of several million additional sockeye from dominant and subdominant brood years (Stockner et al. 1994). Fertilization of Quesnel Lake might have the added benefit of increasing the kokanee population and benefiting the lake's trophy rainbow trout.

Most other Fraser system lakes in the B.C. interior have underutilized rearing capacity in all cycle years, with current escapements substantially lower than those prior to the 20th century (Ricker 1987). Increasing fry recruitment by the appropriate means (increased escapements, fry outplants, spawning channels) would be the most effective means of increasing stock size in these lakes. Most of these lakes (Adams Lake is a prominent exception) are productive enough to produce relatively large sockeye smolts at low fish densities and there would be little additional benefit from fertilization. Once fry recruitment to the lakes has been increased sufficiently to affect sockeye growth or survival, fertilizer applications to some of those lakes (e.g. Takla, Trembleur) would likely accelerate recovery of the stocks.

Central Coast

The eight lakes in the Central Coast area reported here are diverse in terms of their physics and chemistry, but based on currently low escapements, all appear to have underutilized sockeye rearing capacity. Several produce small sockeye smolts even at current low spawner densities and fertilization may assist recovery (e.g. Nimpkish, Woss). On most of the lakes some information gaps need to be filled before initiation or resumption of enhancement activities. Charlotte Lake is inaccessible to anadromous fish but would be an effective sockeye rearing area and is a possible candidate for fry outplants.

Lower Fraser

We report on four lakes in this area (Chilliwack, Harrison, Lillooet, and Pitt). Lillooet Lake's high turbidity, rapid flushing, and high nutrient loading precludes it from being a candidate for fertilizer applications. For the remaining lakes some information gaps need to be filled before decisions about appropriate enhancement techniques can be made. Available data indicate that fertilization would stimulate productivity in each of these lakes, but would likely be of little benefit to sockeye until fry recruitment is increased.

North Coast

Of the 25 lakes we report on in this area, 15 are interior lakes in the Skeena or Nass drainage basins. The interior lakes range widely in terms of surface area, physical environment, trophic status, size of their sockeye stocks, and limiting factors. With some exceptions, most appear to have underutilized rearing capacity for juvenile sockeye. Several (e.g. Johanson, Kitlope, Morice, Sustut) would likely benefit from fertilizer applications even at current escapement levels.

The remaining 10 are coastal lakes located on the mainland, Banks Island, Pitt Island, and the Queen Charlotte Islands. These lakes are relatively small in size, have small sockeye stocks, and appear to have underutilized rearing capacity. They are all fast flushing, organically stained, acidic, and highly oligotrophic. Several have been fertilized in the past and where data are available, appear to have responded positively to fertilizer additions (Hyatt and Stockner 1985). Data are limited on a number of these lakes, but the available data indicates that fertilizer applications would likely benefit the sockeye stocks in several. The pH of some lakes in this area is low enough to be of concern to the viability of their sockeye stocks.

South Coast

Four of the six South Coast area lakes in this report were fertilized for many years (Great Central, Henderson, Hobiton, Kennedy) although only on Great Central Lake is the fertilization presently continuing. In addition, Sproat Lake was fertilized for two years in the mid-1980's. Hyatt and Stockner (1985) reported that size of smolts from both Great Central and Kennedy lakes increased during fertilized years.

V. Acknowledgements

Over the more than 20 years of field investigations that produced the data synthesized in this report, a large number of dedicated people participated in various aspects of the data collection and analysis. Field work often involved working in remote areas from small boats and aircraft and was, and continues to be, frequently uncomfortable and occasionally dangerous. It would be impossible to list all the people who have made valuable contributions to this report and to our understanding of B.C. sockeye nursery lakes, but some must be mentioned. J. Stockner led the Lake Enrichment Program for many years and provided much insight into the role of nutrients in sockeye lake dynamics. Others who made, or continue to make, valuable contributions to our understanding of salmon and their importance to freshwater ecosystems are H. Enzenhofer, K. Hyatt, E. MacIsaac, S. MacLellan, K. Masuda, K. Mullen, B. Nidle, P. Rankin, and K. Stephens.

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Table 1. Geographic and morphometric data from the study lakes.

Lake	Latitude (°N)	Longitude (°W)	Elevation (m)	Surface area (km²)	Mean depth (m)	Water residence time (yr)
BC Interior						
Adams	51°15'	119°30'	404	129	169	10
Anderson	50°38'	122°25'	258	28	140	7.1
Bonaparte	51°15'	120°34'	1168	34	40	
Bowron	53°14'	121°23'	945	10	16	0.6
Chilko	51°16'	124°04'	1172	185	134	16
East Barriere	51°17'	119°47'	640	9.9	48	
Francois	54°02'	125°45'	725	250	87	36
Fraser	54°05'	124°45'	670	54	13	0.8
Momich	51°19'	119°21'	472	2.0	32	0.2
North Barriere	51°20'	119°50'	634	5.2	35	
Quesnel	52°31'	121°00'	715	270	158	11
Seton	50°41'	122°07'	237	24	85	0.8
Shuswap	50°56'	119°17'	346	330	60	2.1
Stuart	54°38'	124°49'	680	359	20	1.7
Takla	55°15'	125°44'	689	246	107	15
Taseko	51°15'	123°35'	1310	31	43	0.9
Trembleur	54°50'	125°05'	686	116	40	1.9
Central Coast						
Charlotte	52°11'	125°20'	1169	66	41	
Elbow	52°05'	125°41'	576	1.5	14	
Lonesome	52°15'	125°44'	482	4.1	14	
Long	51°14'	127°10'	15	21	73	1.1
Nimpkish	50°25'	126°57'	20	37	162	1.4
Owikeno	51°41'	126°55'	15	91	172	2.0
Rainbow	52°07'	125°43'	569	1.7	3.8	
Woss	50°07'	126°37'	150	13	81	3.0
Lower Fraser						
Chilliwack	49°03'	121°25'	625	12	67	1.3
Harrison	49°33'	121°50'	10	220	151	2.3
Lillooet	50°15'	122°30'	195	35	62	0.5
Pitt	49°26'	122°32'	tidal	53	46	1.4
North Coast						
Alastair	54°06'	129°11'	30	6.9	31	0.9
Awun	53°36'	132°35'	16	4.9	47	0.9
Babine	54°27'	125°25'	712	461	61	18
Bear	56°05'	126°49'	805	19	14	1.1
Bonilla	53°31'	130°15'	10	2.3	34	1.0
Curtis	53°30'	129°50'	10	3.0	34	0.6
Devon	53°27'	129°44'	10	1.8	29	1.3
Eden	53°51'	132°43'	21	5.9	43	0.9
Fred Wright	55°58'	128°46'	572	3.9	18	0.3
Ian	53°45'	132°34'	35	20	50	1.1

Table 1. Geographic and morphometric data from the study lakes.

Lake	Latitude (°N)	Longitude (°W)	Elevation (m)	Surface area (km²)	Mean depth (m)	Water residence time (yr)
Johanson	56°35'	126°11'	1444	1.4	16	
Kitlope	53°05'	127°49'	15	12	86	0.5
Kitsumkalum	54°47'	128°47'	122	19	81	
Kitwanga	55°22'	128°07'	376	7.8	5.0	
Lakelse	54°23'	128°33'	137	13	8.0	
Lowe	53°34'	129°33'	10	3.7	25	0.2
Mercer	53°33'	132°52'	8	1.2	15	0.1
Meziadin	56°02'	129°15'	246	36	45	1.9
Morice	54°00'	127°40'	764	96	100	3.8
Morrison	55°14'	126°22'	730	13	21	
Simpson	53°37'	129°33'	15	8.7	57	2.0
Stephens	55°45'	128°34'	487	1.9	11	0.2
Sustut	56°35'	126°27'	1301	2.5	6.0	
Swan	55°46'	128°39'	524	18	36	4.6
Yakoun	53°19'	132°17'	107	8.1	39	2.5
South Coast						
Great Central	49°22'	125°15'	82	51	212	7.3
Henderson	49°05'	125°02'	15	15	109	1.3
Hobiton	48°45'	124°49'	5	3.6	36	1.0
Kennedy	49°04'	125°30'	12	64	33	1.1
Muriel	49°08'	125°36'	11	1.5	22	1.0
Sproat	49°14'	125°06'	29	41	59	8.0

Table 2. Salient physical and chemical variables from the nursery lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

Lake	Data quality[a]	Mean epilimnetic temp (°C)	Thermocline depth (m)	Euphotic zone depth (m)	pH	Total alkalinity (mg $CaCO_3$/L)
BC Interior						
Adams - UF	1	14.6	7.5	13.3	6.97	21.0
- F	2	12.7	8.0	11.6	7.35	20.2
Anderson	2	14.2	18.2	22.6	7.49	46.0
Bonaparte	3	10.4	14.8	13.3	7.04	38.8
Bowron	3		24.5	10.4	7.35	32.9
Chilko - UF	1	8.2	24.2	20.9	7.10	20.2
- F	1	9.3	19.9	20.2	7.20	20.5
East Barriere	2	13.7	6.0	7.8		
Francois	1	13.3	17.2	10.9	7.50	35.0
Fraser	1	15.3	10.6	7.4	7.58	43.3
Momich	3			6.9	7.20	13.0
North Barriere	2	12.3	5.8	7.4		
Quesnel	1	12.4	12.4	15.5	7.51	46.4
Seton	2	13.5	22.4	11.2	7.30	34.1
Shuswap	1	14.9	10.0	12.3	7.41	35.7
Stuart	1	13.6	20.3	6.6	7.80	41.6
Takla	1	11.6	13.7	6.9	7.51	27.9
Taseko	3			1.8		
Trembleur	1	12.2	20.0	6.0	7.62	34.6
Central Coast						
Charlotte	3		15.2	22.1	7.55	12.2
Elbow	3		13.0	7.9	6.67	12.6
Lonesome	3		14.0	11.7	6.80	14.4
Long – UF	1	13.5	10.0	7.3	6.40	3.1
- F	1	13.8	9.3	8.0	6.55	3.6
Nimpkish - UF	1		27.4	11.7	7.00	10.5
- F	1	13.2	25.0	10.2	6.90	
Owikeno	2		31.0	5.3		7.7
Rainbow	3		Iso	9.6	6.82	13.4
Woss	2		18.3	13.7	6.83	8.0
Lower Fraser						
Chilliwack	3			13.5	6.87	6.6
Harrison	1	12.6	21.4	11.2	6.99	13.6
Lillooet	2	11.9	39.3	4.5	6.98	15.7
Pitt	3	12.3	14.9	9.3		
North Coast						
Alastair	2		10.2	13.5		3.2
Awun - F	1	13.9	10.1	5.2	6.30	.
Babine	1	13.4	11.3	6.9	7.51	36.6
Bear	2		7.5	8.8		20.3

Table 2. Salient physical and chemical variables from the nursery lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

Lake	Data quality[a]	Mean epilimnetic temp (°C)	Thermocline depth (m)	Euphotic zone depth (m)	pH	Total alkalinity (mg $CaCO_3$/L)
Bonilla - UF	2			4.2	5.70	0.7
- F	1	13.6	10.5	4.4	5.90	1.0
Curtis - UF	2			6.0	5.80	0.8
- F	1	13.3	8.3	6.3	6.17	1.1
Devon - UF	2			5.8	5.60	0.6
- F	2		7.6	6.1	5.80	0.7
Eden - F	1		13.7	4.4	6.60	
Fred Wright	2		7.0	9.7	7.00	8.9
Ian - F	1	14.3	13.2	3.8	6.10	
Johanson	2	8.3	10.0	21.4	7.16	19.6
Kitlope - UF	2		7.6	7.6	6.22	1.6
- F	1			8.3	6.10	1.5
Kitsumkalum	2	11.0	25.5	3.8	7.15	15.1
Kitwanga	2	14.7	5.7	11.6	7.46	59.5
Lakelse	2	16.0	13.5	7.7	7.33	21.6
Lowe - UF	2		8.3	7.6	5.70	0.8
- F	1		11.5	7.7	5.80	0.5
Mercer - UF	3			6.1	5.30	3.6
- F	2			6.4	6.00	2.6
Meziadin	1		5.4	10.9	7.55	24.5
Morice - UF	2		25.8	19.8	7.00	13.0
- F	2			15.4	7.00	14.7
Morrison	2	13.5	6.2	4.2	7.13	26.4
Simpson	2		11.1	7.2		
Stephens	2		4.8	13.1		13.4
Sustut	2	11.1	4.5	15.1	7.28	26.3
Swan	3		9.6	15.3		13.5
Yakoun - UF	2			7.2		
- F	2	14.4	7.8	6.1		
South Coast						
Great Central - F	1	15.0	9.9	16.2	6.83	12.5
Henderson - F	1	14.1	15.9	10.3	6.85	7.5
Hobiton - UF	2	14.5	9.2	10.8		
- F	1	15.1	8.2	8.4	6.70	5.2
Kennedy - UF	1	15.0		9.4	6.97	10.7
- F	1	14.6	8.9	9.1	7.27	13.3
Muriel	2	17.3	4.8	5.6		
Sproat - UF	1	15.1		20.2	7.00	22.7
- F	2	17.0	10.3	20.0	6.80	24.6

[a] Data Quality

1 = Multiple years of monthly data collection
2 = One year of seasonal data collection
3 = Surveys - sampled 1-3 times

Table 3. Salient chemical variables from the nursery lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

		Nitrate (μg N/L)			Total phosphorus (μg/L)	
Lake	Data quality[a]	Spring overturn	Mean epilimnetic	Seasonal minimum	Spring overturn	Mean epilimnetic
BC Interior						
Adams - UF	1	101	66	18	1.6	1.6
- F	2	89	57	16		
Anderson	2	50	21	4.5	4.7	5.8
Bonaparte	3	1.9	1.6	1.0	6.4	5.0
Bowron	3	90[b]	56		4.0[b]	3.8
Chilko - UF	1	21	12	2.1	1.9	2.5
- F	1	18	12	3.0	2.0	3.8
East Barriere	2	16	6.0	4.8	8.6	4.1
Francois	1	32	10	1.6	6.4	5.8
Fraser	1	3.0	3.3	0.9	17.8	15.4
Momich	3	52[b]	3.5			3.5
North Barriere	2	21	16	<1	5.7	4.2
Quesnel	1	104	68	38	2.7	2.8
Seton	2	30	9.0	2.6	10.0	7.2
Shuswap	1	75	18	1.1	6.4	5.1
Stuart	1	37	14	3.3	9.8	7.4
Takla	1	74	48	29	4.7	4.9
Taseko	3		24			
Trembleur	1	57	34	21	8.8	8.1
Central Coast						
Charlotte	3	11[b]	1.7			3.8
Elbow	3	54[b]	4.8			4.6
Lonesome	3	31[b]	2.1		6.1[b]	6.1
Long	1	62	19	<1	3.4	1.8
Nimpkish	1	48	34	28		2.1
Owikeno	2	100	38	2.0		
Rainbow	3		2.4			4.4
Woss	2	38	11	3.0	1.2	1.1
Lower Fraser						
Chilliwack	3	83	69	38	2.1	3.6
Harrison	1	59	47	26	4.0	5.3
Lillooet	2	63	29	1.2	9.6	
Pitt	3	117	78	40	3.3	3.2
North Coast						
Alastair	2	106	2.8	<1		
Awun - F	1	34	15	2.9	2.3	3.6
Babine	1	73	26	4.3		5.5
Bear	2	40	2.1	1.6		

Table 3. Salient chemical variables from the nursery lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

Lake	Data quality[a]	Nitrate (µg N/L) Spring overturn	Nitrate (µg N/L) Mean epilimnetic	Nitrate (µg N/L) Seasonal minimum	Total phosphorus (µg/L) Spring overturn	Total phosphorus (µg/L) Mean epilimnetic
Bonilla - UF	2	8.0	3.0	<1	2.1[b]	
- F	1	7.1	2.0	<1	2.1	5.0
Curtis - UF	2	27	10	<1	2.3[b]	
- F	1	20	4.8	<1	2.3	5.2
Devon - UF	2	20	5.0	<1	2.3	
- F	2		1.0	1.0		
Eden - F	1	50	33	18	2.2	3.8
Fred Wright	2	1.0	4.8	<1		
Ian - F	1	33	29	25	2.2	3.4
Johanson	2	1.7	1.9	1.2	2.3	3.3
Kitlope - UF	2	64	19	6.1	1.5	
- F	1	66	18	8.0		
Kitsumkalum	2	81	35	12		
Kitwanga	2	2.2	1.5	0.7	10.8	7.4
Lakelse	2	31	8.1	<1	5.1	5.4
Lowe - UF	2	23	7.0	4.4	1.2	
- F	1	21	9.0	2.0		
Mercer - UF	3	13	9.0	<1	2.0	2.0
- F	2		15			
Meziadin	1	219	131	40		
Morice - UF	2	43	31	22		
- F	2	40	26	16	1.0	1.5
Morrison	2	34	10	1.3	8.5	6.9
Simpson	2	26	11	<1	1.0	1.6
Stephens	2	8.0	3.1	<1		6.2
Sustut	2	<1	<1	<1	5.6	6.5
Swan	3	15	8.1	<1		5.5
Yakoun - UF	2	36	7.6	<1	1.0	1.9
- F	2	8.0	4.0	<1	2.3	4.0
South Coast						
Great Central - F	1	32	6.9	<1	<1	1.8
Henderson - F	1	26	10	<1	1.5	3.2
Hobiton - UF	2	31	6.5	1.0	1.5	1.9
- F	1	25	7.5	<1	2.7	3.6
Kennedy - UF	1	28	11	<1	1.5	1.5
- F	1	50	11	1.1	1.9	4.5
Muriel	2	29	1.0	<1	1.2	2.6
Sproat - UF	1	21	3.3	<1	1.2	1.2
- F	2	36	5.2	<1	1.5	1.5

[a] - Data Quality

1 = Multiple years of monthly data collection

2 = One year of seasonal data collection

3 = Surveys - sampled 1-3 times

[b] - Spring overturn data are not available. Data are hypolimnetic data.

Table 4. Salient biological variables from the sockeye lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

Lake	Data quality[a]	Chlorophyll (μg/L)	Daily PR (mg C/m²)	Zooplankton biomass (mg dry wt/m²) Total	Zooplankton biomass (mg dry wt/m²) *Daphnia*
BC Interior					
Adams - UF	1	0.81	111	1004	374
- F	2	1.07	113	921	292
Anderson	2	1.04	276	2622	1047
Bonaparte	3	1.22	131	816	301
Bowron	3	1.51		646	
Chilko - UF	1	0.70	82	711	10
- F	1	0.96	98	1065	123
East Barriere	2	1.49		307	170
Francois	1	1.92	163	1202	356
Fraser	1	4.22	332	1930	998
Momich	3	2.13		412	
North Barriere	2	5.00		191	44
Quesnel	1	1.03	102	829	237
Seton	3	1.49	219	422	219
Shuswap	1	1.81	171	1005	400
Stuart	1	1.92	138	1410	139
Takla	1	1.02	55	562	91
Taseko	3	0.35		120	
Trembleur	1	1.40	84	1134	231
Central Coast					
Charlotte	3	0.47	76	1459	666
Elbow	3	0.75	54	1089	276
Lonesome	3	0.60	78	1982	1572
Long – UF	1	2.24	70	180	
- F	1	2.48	297	420	
Nimpkish - UF	1	0.80	80	73	
- F	1	1.78		260	
Owikeno	2	0.94	78	155	
Rainbow	3	0.63	55	674	644
Woss	2	0.96	122	191	
Lower Fraser					
Chilliwack	3	0.60	88	219	24
Harrison	1	0.75	107	572	<1
Lillooet	2	1.63	144	139	<1
Pitt	3	1.20	72	244	<1
North Coast					
Alastair	2	2.74	209	198	
Awun - F	1	1.56		956	
Babine	1	2.20	140	1031	28
Bear	2	1.75	144	1849	
Bonilla - UF	2	1.04	122	281	

Table 4. Salient biological variables from the sockeye lakes. Data are from unfertilized lakes unless otherwise specified (UF=unfertilized, F=fertilized).

	Data	Chlorophyll	Daily PR	Zooplankton biomass (mg dry wt/m^2)	
Lake	quality[a]	(µg/L)	(mg C/m^2)	Total	*Daphnia*
- F	1	4.70	291	782	
Curtis - UF	2	1.24	103	80	
- F	1	4.02	153	166	
Devon - UF	2	1.79	103	77	
- F	2	4.57	160	108	
Eden - F	1	1.63		612	
Fred Wright	2	1.75	132	768	
Ian - F	1	1.10		605	
Johanson	2	0.97	66	17	<1
Kitlope - UF	2	0.55	54	53	
- F	1	0.97	65	88	
Kitsumkalum	2	0.60	33	97	<1
Kitwanga	2	1.53	265	1770	1113
Lakelse	2	1.38	74	718	66
Lowe - UF	2	1.22	107	180	
- F	1	1.34	83	815	
Mercer - UF	3	2.50		225	
- F	2	1.66			
Meziadin	1	1.46	171	516	
Morice – UF	2	0.79	86	554	
- F	2	1.18	98	909	
Morrison	2	2.32	108	678	13
Simpson	2	1.12	64	387	
Stephens	2	1.45		1034	
Sustut	2	1.43	88	17	3
Swan	3	0.92	93	948	
Yakoun – UF	2	1.69		184	
- F	2	3.28		140	
South Coast					
Great Central - F	1	1.06	123	435	
Henderson - F	1	2.52	203	469	
Hobiton - UF	2	1.22		292	
- F	1	1.84	114	460	
Kennedy - UF	1	1.10	71	227	
- F	1	2.38	265	364	
Muriel	2	0.93		323	
Sproat - UF	1	0.60	84	285	
- F	2	1.08	184	590	

[a] - Data Quality
1 = Multiple years of monthly data collection
2 = One year of seasonal data collection
3 = Surveys - sampled 1-3 times

Table 5. Age-0 *O. nerka* fall size and density. Data are from the most recently available 10 years. These include both sockeye and kokanee where present.

Lake	Weight (g)			Density (N/ha)		
	Max.	Mean	Min.	Max.	Mean	Min.
B. C. Interior						
Adams[a]		2.6			<1	
-fertilized		3.5			30	
Anderson[b]		1.1			1057	
Bonaparte[c]		3.2			120	
Bowron						
Chilko[a]	6.2	4.3	3.3	1990	951	279
-fertilized	7.3	5.5	3.9	1985	1355	643
East Barriere[c]		2.0			400	
Francois	8.1	5.2	2.9	243	164	85
Fraser	5.5	4.5	3.4	12337	3847	1265
Momich						
North Barriere		2.9			3589	
Quesnel	9.4	4.1	2.7	2590	1378	201
Seton[b]		5.0			289	
Shuswap	3.6	2.4	1.5	4868	2025	358
Stuart	4.4	3.4	1.8	547	418	392
Takla	3.9	3.1	2.5	290	252	213
Taseko						
Trembleur	5.8	5.1	3.7	480	390	299
Central Coast						
Charlotte					0	
Elbow						
Lonesome[d]		1.5			293	
Long[e]	2.4	1.1	0.5			
Nimpkish[f]		1.5			337	
Owikeno[g]		0.7				
Rainbow						
Woss[g]		1.5			537	
Lower Fraser						
Chilliwack		4.0			765	
Harrison	5.9	4.5	2.4		120	
Lillooet	5.1	3.6	1.7		660	
Pitt	9.1	6.5	4.6			
North Coast						
Alastair		1.7			1994	
Awun						
Babine[a]	4.3	3.6	2.9	1445	787	464
Bear		3.9			132	
Bonilla[f]		1.6			1222	

Table 5. Age-0 *O. nerka* fall size and density. Data are from the most recently available 10 years. These include both sockeye and kokanee where present.

Lake	Weight (g)			Density (N/ha)		
	Max.	Mean	Min.	Max.	Mean	Min.
Curtis[f]		1.1			1589	
Devon[f]	3.4	2.6	1.9	3102	2903	2705
Eden[f]						
Fred Wright[f]	4.1	3.1	2.1		3992	
Ian[f]						
Johanson		0.9			321	
Kitlope[f]		2.1			310	
Kitsumkalum		1.6			125	
Kitwanga		2.4			77	
Lakelse		6.1			311	
Lowe[g]		1.2			150	
Mercer						
Meziadin[h]	2.0	1.9	1.5	2199	1662	650
Morice		0.8			86	
Morrison		4.3			377	
Simpson						
Stephens[g]		3.1			250	
Sustut		1.0			1779	
Swan		1.3			475	
Yakoun						
South Coast[i]						
Great Central[i]	6.6	3.7	2.3	3800	1883	780
Henderson[i]	6.9	3.6	1.2	3715	1503	755
Hobiton[i]	5.4	4.0	2.5			
Kennedy[i]	6.4	2.9	1.9	4071	1834	972
Muriel[i]	7.6	5.5	3.5			
Sproat[i]	4.8	3.8	2.2	4970	2481	890

Blanks indicate no data available. [a] Smolt density in Chilko; fry density in Adams; smolt size in both lakes. [b] from 2000 surveys only kokanee were separated out by Sr in otolith origin . [c] Kokanee only -no sockeye access. [d] D. Rutherford, DFO, Pers com. [e] Fall fry sizes from Hyatt et al 2000. [f] Smolt sizes from Hyatt and Stockner (1985). [g] Data from Simpson et al. (1981). [h] Fry size from McCreight et al.(1993). Fry density from B. Stables, Shuksan Fisheries Consulting, P.O. Box 485, Sumas, WA 98295,USA. [i] K. Hyatt and P. Rankin, DFO, Pers Com.

Table 6. Sockeye escapement data and optimum escapement predictions for the study lakes. Escapement data are from the most recently available 10 years of data.

Lake	Total escapement (1000's)			Spawner density (N/ha)			PR model optimum escapement (1000's)
	Min	Mean	Max	Min	Mean	Max	
BC Interior							
Adams	<0.1	11	72	<0.0	0.8	5.6	483
Anderson[a]							260
Bonaparte	0.0	0.0	0.0	0.0	0.0	0.0	150
Bowron	1.2	8.7	34	1.2	8.7	34.4	
Chilko	452	763	1040	24.4	41.3	56.2	513
East Barriere	0.0	0.0	0.0	0.0	0.0	0.0	
Francois	2.1	37	201	0.1	1.5	8.0	1366
Fraser	55	163	372	10.3	30.3	61.9	601
Momich	<0.1	2.1	9.4	<0.0	10.7	46.8	
North Barriere	5.7	12	33	11.0	23.4	63.0	
Quesnel	8.9	687	2615	0.3	25.4	96.8	931
Seton[a]	4.5	41	104				177
Shuswap	7.0	540	1510	0.2	16.4	45.8	1897
Stuart	22	279	1407	0.6	7.8	39.3	1659
Takla	4.2	96	578	0.2	3.9	23.5	453
Taseko	0.0	1.0	3.0	0.0	0.3	1.0	
Trembleur	29	144	508	2.5	12.5	44.0	326
Central Coast							
Charlotte	0.0	0.0	0.0	0.0	0.0	0.0	169
Elbow[b]							2
Lonesome[b]	15	33	55				11
Long	5.9	117	260	2.8	55.9	123.8	49
Nimpkish[c]	20	81	237				100
Owikeno	3.6	215	587	0.4	23.6	64.4	239
Rainbow[b]							3
Woss[c]							53
Lower Fraser							
Chilliwack	0.4	2.8	8.1	0.4	2.3	6.8	36
Harrison[d]	31	189	427				796
Lillooet[d]							170
Pitt	5.6	31	77	1.1	5.8	14.4	130
North Coast							
Alastair	5.0	8.3	12	7.2	12.0	18.1	48
Awun	0.1	2.2	5.5	0.2	4.5	11.2	
Babine	674	1327	2106	14.6	28.8	45.7	2172
Bear	0.8	2.6	5.0	0.4	1.4	2.7	91
Bonilla	0.6	1.3	3.0	2.6	5.8	13.0	9
Curtis	0.3	4.5	8.2	1.0	14.9	27.3	10
Devon	<0.1	3.1	6.0	0.3	17.3	33.3	6

Table 6. Sockeye escapement data and optimum escapement predictions for the study lakes. Escapement data are from the most recently available 10 years of data.

Lake	Total escapement (1000's)			Spawner density (N/ha)			PR model optimum escapement (1000's)
	Min	Mean	Max	Min	Mean	Max	
Eden	0.1	2.5	5.0	0.2	4.2	8.5	
Fred Wright	1.0	7.1	16	2.6	18.2	41.0	17
Ian	0.1	1.0	3.5	0.1	0.5	1.8	
Johanson	<0.1	0.6	2.6	<0.0	4.4	18.6	3
Kitlope[e]	8.0	14	20				22
Kitsumkalum	1.0	3.3	5.5	0.5	1.8	3.0	20
Kitwanga	<0.1	0.4	2.2	<0.0	0.5	2.8	75
Lakelse	1.0	4.9	13	0.8	3.7	9.5	33
Lowe	1.0	3.2	6.0	2.7	8.7	16.2	13
Mercer	0.8	2.1	4.0	6.7	17.2	33.3	
Meziadin	50	228	592	13.9	63.4	164.5	207
Morice	1.0	20.7	41	0.1	2.2	4.3	211
Morrison	0.8	5.7	15	0.6	4.3	11.1	48
Simpson							19
Stephens							
Sustut	0.1	1.0	2.6	0.4	4.0	10.4	5
Swan[f]	2.0	7.7	13				55
Yakoun	2.2	6.4	12	2.8	8.0	14.5	
South Coast							
Great Central	64	196	437	12.5	38.5	85.7	212[g]
Henderson	3.0	36	120	2.0	24.0	80.0	103[g]
Hobiton	3.3	7.6	13	9.3	21.2	35.4	14[g]
Kennedy	3.4	11	25	0.5	1.8	3.9	130
Muriel	<0.1	1.2	2.6	0.3	7.7	17.3	
Sproat	102	163	211	25.0	39.7	51.5	115

[a] Escapements to Seton and Anderson are combined (see Seton for total)

[b] Escapements to Lonesome, Elbow and Rainbow lakes are combined (see Lonesome for total)

[c] Escapements to Nimpkish and Woss lakes are combined (see Nimpkish for total).

[d] Escapements to Lillooet and Harrison lakes are combined (see Harrison for total).

[e] Escapements to Kitlope and Kimsquit (not shown) lakes are combined.

[f] Escapements to Swan, Club (not shown), and Stephens lakes are combined (see Swan for total).

[g] PR model predictions are for fertilized years

Table 7. List of the lakes in this report with limiting factors and enhancement/restoration options presented. The legend appears after the table. Numbers in bold signify that data available are sufficient to make unequivocal recommendations. Numbers not in bold indicate more data are required to confirm the suggested recommendations. In all cases, data needed to assess whether a particular project is successful include escapements, juvenile sockeye numbers and size, and a variety of limnological data (**15,16,17**).

Region and lake	Limiting factor(s)	Type of enhancement/ restoration indicated	Rationale for enhancement	Information needed to determine project feasibility and success	Comments
BC Interior					
Adams	**1,2,4**	**7,8,10**	**12**		Lake fertilization in the dominant brood year is underway
Anderson	1,2,3,6	7,8,9	12,13,14	**15,16,17**	Current sockeye utilization of the lake is unknown
Bonaparte	**1**,2,4,**6**	**8**,10	**14**	**15,16,17**	Potential spawning ground capacity is unknown
Bowron	?	?	?	**15,16,17**	
Chilko	**3,4,5**	**10**	**12**	**15,16**	
East Barriere	**1,2,6**	8,10	**14**	**15,16,17**	Not currently accessible to anadromous fish
Francois	**1,2**	**7,8**	**12**	**15**	
Fraser	**1**	**7,9**	**12**	**15**	
Momich	1,3,4,5	7,8,10	13	**15,16,17**	
North Barriere	3,4,5	10	12	**15,16,17**	
Quesnel[a]	**3,4,5**	**10**	**12**	**15**	
Quesnel[b]	**1**	**7**	**13**	**15**	
Seton	1,2,3,4	?	?	**15,16,17**	
Shuswap	**1,3,4**	7,9	**12,13**	**15**	
Stuart	**1**	**7,8**	**12,13**	**15**	
Takla	**1,4**	**7,8,10**	**12**	**15,16**	Fertilization would be beneficial at higher fry densities
Taseko	1,3,**6**	?	?	**15,16,17**	Highly turbid from glacial inflows
Trembleur	**1**	**7,8**	**12,13**	**15**	
Central coast					
Charlotte	**1**	**8**	**14**		Not accessible to anadromous fish
Elbow	?	?	?	**15,16,17**	
Lonesome	?	?	?	**15,16,17**	
Long	**1**,2,**3,4**	**7,8**,9,10	12,13	**15,16**	Fertilization would likely be beneficial at higher fry densities
Nimpkish	**1,3,4**	**7,8**,10	**12,13**	**15,16**	
Owikeno	**1,2,3**,4	**7**,8,10	**13**	**15,16,17**	
Rainbow	?	?	?	**15,16,17**	
Woss	**1,3,4**	**7,8,10**	**12,13**		Lake fertilization is underway

Table 7. List of the lakes in this report with limiting factors and enhancement/restoration options presented. The legend appears after the table. Numbers in bold signify that data available are sufficient to make unequivocal recommendations. Numbers not in bold indicate more data are required to confirm the suggested recommendations. In all cases, data needed to assess whether a particular project is successful include escapements, juvenile sockeye numbers and size, and a variety of limnological data (**15,16,17**).

Region and lake	Limiting factor(s)	Type of enhancement/ restoration indicated	Rationale for enhancement	Information needed to determine project feasibility and success	Comments
Lower Fraser					
Chilliwack	1,3,4	**7,8**,10	**13**	**15,16,17**	Fertilization would likely be beneficial at higher fry densities
Harrison	**1**	7,9,10	**12**	**15,16,18**	Fertilization would likely be beneficial at higher fry densities
Lillooet	**3,5,6**	None	**12**	**15,16**	Turbid water, rapid flushing, and high nutrient loading
Pitt	**1,2,3,4**	**7,8,10**	**12**	**15,16**	High growth rates/low survival; competitive interactions
North Coast					
Alastair	**3,5,6**	**11**	**13**	**15,16**	High stickleback numbers
Awun	?	?	?	**15,16,17,18**	Only fertilized data are available
Babine	5	None			Most productive capacity currently utilized
Bear	**1,2**	**7,8**	**13**	15	
Bonilla	**1,3,4,6**	**7,8,10**	**13**	**15,16,17,19**	Previous fertilization was successful. Low pH
Curtis	**1,3,4,6**	**7,8,10**	**13**	**15,16,17,19**	Previous fertilization was successful. Low pH
Devon	**1,3,4,6**	**7,8,10**	**13**	**15,16,17,19**	Previous fertilization was successful. Low pH
Eden	?	?	?	**15,16,17,18**	Only fertilized data are available
Fred Wright	**1**	**7,8**	**13**	**15,16**	
Ian	?	?	?	**15,16,17,18**	Only fertilized data are available
Johanson	**1,3,4**	**7,10**	**13**	**15,16**	
Kitlope	**1,3,4**	**7,8,10**	**12**	**15,16**	Previous fertilization was successful
Kitsumkalum	**1,2,3,6**	**7**	**13**	**15,16**	
Kitwanga	**1,2,6**	**7,8**	**13**	**15,16,18,19**	Seasonally low hypolimnetic oxygen
Lakelse	**1**	**7,8**	**13**	**15,16,19**	Degree of competition from mysids is unknown
Lowe	**1,3,4**	**7,8,10**	**13**	**15,16**	Previous fertilization was successful.
Mercer	?	?	?	**15,16,17,18**	
Meziadin	3,5	10	12	**15,16,17**	
Morice	**1,3,4**	**10**	**12**	**15,16,17**	
Morrison	**1**	**7,8**	**13**	**15,16**	
Simpson	**1**	8	14	15,16	
Stephens	**1**	?	13	**15,16,17**	
Sustut	**1,3,4**	**7,10**	13	**15,16**	

Table 7. List of the lakes in this report with limiting factors and enhancement/restoration options presented. The legend appears after the table. Numbers in bold signify that data available are sufficient to make unequivocal recommendations. Numbers not in bold indicate more data are required to confirm the suggested recommendations. In all cases, data needed to assess whether a particular project is successful include escapements, juvenile sockeye numbers and size, and a variety of limnological data (**15,16,17**).

Region and lake	Limiting factor(s)	Type of enhancement/ restoration indicated	Rationale for enhancement	Information needed to determine project feasibility and success	Comments
Swan	1,3,4	?	13	**15,16,17**	
Yakoun	1,3,4	?	13	**15,16,17**	
South Coast					
Great Central	**3,4**	**10**	**12**		Unfertilized data needed
Henderson	**1,2**,3,4	**7,8,9**,10	**12,13**	**15,16**	Unfertilized data needed
Hobiton	**1,3,4**	**7,10**	**12**		Unfertilized data needed
Kennedy	1,2,**3,4**	7,8,9,**10**	**12,13**	**15,16,18**	
Muriel	1,3,4	?	13	**15,16,17**	
Sproat	3,**4**,5	**10**	**12**	**15,16**	

[a] - dominant and subdominant brood years

[b] – nondominant brood years

Limiting factors - factors limiting sockeye production

1	Low escapements and fry recruitment
2	Low spawning ground capacity or quality
3	Low in-lake growth and/or survival
4	Nutrient limitation
5	Rearing capacity reached or exceeded in some years
6	Other

Type of enhancement/restoration indicated

7	Increased escapement through harvest reduction
8	Increased fry recruitment - (outplants)
9	Increased fry recruitment - (spawning channel or spawning ground improvements)
10	Lake fertilization
11	Predator/competitor control

Rationale for enhancement

12	Enhancement Larger stock with probable short-term economic benefit
13	Restoration Conservation of small or weak stock - possible long-term economic benefit
14	Creation of new run

Information needs - types of data required prior to implementation

15	Escapement
16	Limnetic fish abundance and growth rates
17	Limnology (includes nutrient chemistry, plankton biomass and productivity)
18	Spawning ground capacity
19	Other